THE ROLE OF THE RIGHT HEMISPHERE IN SPEECH PROCESSING

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I declare that this thesis has been composed by me and that the work reported here is my own.

Abstract

Literature is reviewed which suggests that the right hemisphere has some speech processing ability and six experiments are described which sought to provide conditions under which this speech processing ability might be demonstrated. These conditions included practice, the use of a secondary verbal task and the direction of attention to either the right or the left ear, as well as the manipulation of several other task variables. In addition, a manual response (reaction time) was used in all the experiments in an attempt to provide the right hemisphere with an accessible means of expression.

The results provided no evidence that the right hemisphere could process speech except in the case of certain individuals who showed a right ear advantage on a dichotic recall task but a left ear advantage on a dichotic recognition task, suggesting that in these individuals the right hemisphere could both process a verbal input and initiate a response.

No significant sex differences were found either in direction or in magnitude of ear advantage. A strong bias was revealed towards attending to the right ear input in the absence of specific instructions to do so, such that when subjects were instructed to attend to this input there was no significant decrease in reaction time.

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Chapter 1

1. Introduction

There is a great deal of evidence, derived both from observations of brain-damaged and split-brain patients and from controlled laboratory investigation, to suggest that there are functional differences between the two hemispheres of the human cortex, these differences being most consistently shown in right-handed individuals. The left hemisphere appears to possess a processor which can decode verbal inputs whereas the right hemisphere appears to be better able to process non-verbal and visuo-spatial stimuli. Much of the evidence supporting such a description of the distribution of functions between the two hemispheres will be discussed in the course of this report, but a few examples will be given here.

Kimura (1961a, 1961b), using the dichotic listening technique, found a right ear advantage (REA) for verbal material and later (1964) found a left ear advantage (LEA) for musical material. Dichotic presentation of stimuli has since been used extensively to examine the relative contributions of the two hemispheres, as reflected by direction of ear advantage, to the processing of a wide variety of inputs.

Taking a different approach, that of analysis of auditory evoked potentials, Wood et al (1971) presented two tasks to their subjects, one requiring analysis of acoustic parameters (direction and extent of second and third formant transitions) important for making a linguistic decision, the other requiring analysis of an acoustic parameter (fundamental frequency) which provided no linguistic information at the phoneme level. The syllable /b/-low (initial F_0 = 104 Hz) was common to both tasks and was used for comparison of evoked potentials. They found that evoked potentials differed over the left hemisphere for these two tasks but were identical over the right hemisphere, reflecting differing neural activity in the left hemisphere during analysis of linguistic or nonlinguistic parameters of the same acoustic signal.

A similar pattern is reported from work using visual rather than auditory stimuli. Kimura (1966), for instance, found that when normal subjects were shown stimuli in only one visual field, letters were more accurately recognised when presented to the right field than when presented to the left whereas non-alphabetic stimuli were better recognised after presentation to the left field. She concluded that the left hemisphere is important for the identification of verbal-conceptual forms whereas the right hemisphere is predominant for processing nonverbal stimuli.

Using a different technique, based on the tendency of each hemisphere to complete patterns beyond the vertical mid-line in split-brain patients, Levy et al (1972) found that subjects chose stimuli which had been presented to the left visual field when the required response was manual (pointing) but favoured the right half of the stimulus when they had to respond verbally. The stimuli used were photographs of faces, nameless forms, drawings of familiar objects and chain patterns, so clearly, unlike in the earlier examples, in this case it was not the processing of a verbal input which was associated with left hemisphere involvement but rather 'the left hemisphere become dominant when some form of verbal and/or conceptual, symbolic transformation was required. When immediate recognition and memory of visual shape was the only requirement, even though a stimulus possessed a well-known name, the right hemisphere dominated.'

Other definitions of the difference between the hemispheres have been proposed, these descriptions resulting from attempts to penetrate the nature of the critical differences between the processing demands of those tasks in which the left hemisphere appears to be primarily involved and those which involve the right hemisphere. Thus it has been suggested that typically (but not invariably) serial processing is carried out within the left hemisphere and parallel processing within the right (Cohen 1973) or that the left hemisphere is involved in analytic processing whereas the right is involved in Gestalt processing (Levy-Agresti & Sperry 1968; Sperry 1970; Trevarthen 1973; Patterson & Bradshaw 1975).

Running alongside all the evidence that speech is processed in the left hemisphere are a number of reports, in most cases from studies of the brain-damaged, of speech processing and, more rarely, of speech output, apparently initiated by the right hemisphere. It is with this issue, the speech processing ability of the right hemisphere, that the present paper is concerned and later in this report six experiments will be described which attempted to provide a range of stimulus and response conditions in which any right hemisphere speech processing capacity might be demonstrated. Before turning to these experiments, however, a variety of reports of right hemisphere involvement in verbal processing will be reviewed.

Evidence of right hemisphere verbal processing falls into two categories: (i) comprehension of verbal inputs, either visual or auditory; (ii) verbal output, either vocal or in writing.

2. Comprehension of verbal inputs, either visual or auditory, by the right hemisphere

Gazzaniga & Sperry (1967), examining the language capacity of each hemisphere in three split-brain patients, found a right hemisphere ability to comprehend both visual and spoken verbal inputs when a response could be expressed by the left hand i.e. by pointing to or retrieving a correct item, by button pressing or by selection by touch. Thus they found for example that if a picture, for instance of a ship, was presented to the left visual field, subjects would deny having seen anything. However, when urged to let the left hand try, they would pick up the card with 'ship' written on it, from a series of ten cards. Or again, if the examiner read for example the phrase 'Used to tell the time' and then flashed five words in succession in the left visual field the patients could make the correct manual response to the word 'clock'. However, when one of them was asked what he had seen, the reply was 'watch'. Levy et al (1971) also found evidence of right hemisphere comprehension of visually presented words: this report will be discussed more fully in the next section, since in this case subjects were able to respond in writing.

Using an auditory input, Milner et al (1968) found that the right hemisphere could program the left hand to obey, for instance, the instruction : 'Now pick up the paper clip', the instruction being presented dichotically to the left ear. If asked to name this object the subject would respond with the name that had been presented simultaneously to the right ear. Nebes & Sperry (1971) asked a commissurotomy patient to pick out an object (unseen) that 'Makes things look bigger'. The patient responded by retrieving a magnifying glass with his left hand. This was reported as 'a telescope'.

There are also a number of reports of comprehension of speech in patients either after left hemispherectomy (Smith & Burklund 1966; Smith 1966; Gott 1973) or after right-sided amobarbital injection (Kinsbourne 1971). These reports will be discussed at greater length in the next section, on verbal output, since in all these cases some form of vocal expression is also reported. Finally, there are some interesting reports of verbal processing apparently mediated by the right hemisphere in normal subjects when the left hemisphere is overloaded. Hellige & Cox (1976) and Hellige (1978) found that the size of the right field advantage for words was reduced when there was a concurrent verbal memory load and Hellige et al (1979) found faster reaction times to right visual field stimuli (same name letter pairs) when there was no additional verbal memory load but faster reaction times to left visual field stimuli when there was a concurrent task in which 2, 4 or 6 nouns had to be remembered.

3. <u>Verbal output, either vocal or in writing, initiated by the right hemisphere</u>

Levy et al (1971) found that a commissurotomy patient was able, with the left hand, to arrange plastic letters in a sequence to spell a word or even to make some progress at writing, again with the left hand, the name of an object previously presented to that hand. They report also another patient who was able to write down, with his left hand, 12 of 39 printed nouns presented to the left visual field. On 10 of these occasions he either could not name or incorrectly named the word he had just written. In another experiment when the word 'sit' was presented to the left visual field he wrote 'si', stopped, added 'mp' and said 'jump'. 'Jump' was a word he knew to be included in the series. The authors suggest that at least part of the right hemisphere's linguistic deficiency is due to the left hemisphere's dominance over the motor mechanisms for language expression.

On the other hand, in the one report of right hemisphere speech output in normal subjects, Geffen et al (1973) found that while usually the response 'Bonk' was faster to target digits presented to the right visual field, when a secondary, verbal, task had to be performed, digits in the left visual field received faster responses, suggesting both that the right hemisphere could process the visual input and that it could initiate the vocal responses.

John Hughlings Jackson (Taylor 1932) constructed a model of hemispheric asymmetry for speech which although not described in altogether the same terms as would be used today nonetheless provides an interesting summary. He writes:

> 'I hope to show two things - (1) that both halves are alike, in so far that each contains processes for words; (2) that they are unlike in that the left only is for use of words in speech and the right for 'other processes in which words serve'.... the right hemisphere is the one for the most automatic use of words, and the left the one in which automatic use of words merges into voluntary use of words - into speech'. (p. 130)

> 'The speechless man retains, to some extent, the power of uttering words; we ought rather to say that words come out of him automatically on fit occasions. He can't <u>say</u> what he <u>utters</u>. It is plain that he has somewhere in him processes for words; but the facts that they are uttered only under excitement and that they are nearly always well-organised formulae, and that the patient cannot repeat them, show that they are not speech... We may fairly conclude that they stand betwixt speech proper and the most automatic use of words as in receiving speech of others'. (p. 136)

> 'These utterances show that the man does utter words involuntarily who cannot talk voluntarily. I would here remark again, however, that such utterances are nearly always formulae which have, by frequent repetition and wide association, become automatic in an extreme sense of the word, and which, although possibly at first laboriously acquired by one (the left) side of the brain, have become 'deposited' on both sides - in fact, have become historical - part of the organism, which is a two-sided one. Much of our talk is made up of acquired forms. There is mannerism on a very large scale. I might instance that speechless patients sometimes retain power to sing, which is at the least a more automatic process than speech. I have also instanced that inherited automatic movements (such as those for respiration), emotional movements (as smiling), escape when a man is rendered speechless; and I have pointed out that..... the inference is that the processes for all these have a (an equal?) representation in each cerebral hemisphere. I think that the highest psychical processes have not an equal - at all events, not a similar - representation in the two hemispheres'. (p. 222)

Thus Smith (1966; Smith & Burklund 1966) found that a left hemispherectomee could follow simple verbal commands immediately after hemispherectomy but his 'attempts to reply to questions immediately after operation were totally unsuccessful. He would open his mouth and utter isolated words, and after apparently struggling to organize words for meaningful speech, recognized his inability and would utter expletives or short emotional phrases (e.g. 'Goddamit!). Expletives and curses were well articulated and clearly understandable. However, he could not repeat single words on command or communicate in 'propositional' speech until 10 weeks post-operatively' and even eight months after hemispherectomy 'expressive speech remains severely impaired'. Smith further reports that in the fifth post-operative month the patient showed sudden recall of whole familiar songs and 'in the seventh month after surgery, he sings with litte hesitation and few errors in articulation'.

Similarly Gott (1973) found that her patient, a 12-year old girl who was tested two years after left hemispherectomy, was able to follow such verbal directions as 'Put an X on the picture which shows what we sleep in' and 'Draw a cat under the table'. She was able to give the correct 'yes' or 'no' answer to statements such as: 'Baby elephants can read' and 'Rabbits can hop and jump'. Gott concluded that 'auditory comprehension of speech was superior to other modes of language abilities with expressive speech being the least developed'. She also observed that her patient was able to sing entire songs and was far superior at expressing herself through singing than through ordinary speech. When asked to define the word 'spangled', this patient 'immediately placed her hand over her heart, sang 'God Bless America' in its entirety, then stated 'Now that is what it is''.

A further contribution to this discussion comes from research into ictal dysphasia and ictal speech automatisms. It is reported that in the former condition, in which the subject, while still conscious, is unable to express himself in the right words, the associated seizures usually originate in the dominant hemisphere. On the other hand ictal speech automatisms, utterances occuring at the beginning of- or during an epileptic seizure of identifiable words or phrases which are linguistically correct but for which the subject is subsequently amnesic, may arise with seizures originating in either hemisphere but perhaps slightly more frequently with seizures originating in the minor hemisphere (Falconer 1967). Chase et al (1967) studying the effect of delayed auditory feedback (DAF) on the ictal speech automatisms of a patient during a seizure found that such speech was not affected by DAF. Further,

> 'the ability to utter the word 'damn' in a normal fashion under DAF conditions, even after termination of the seizure, suggests that swearing is generated by different neurophysiological processes than are used to generate propositional speech. It is possible that words used for swearing, and other interjectional utterances used to express emotion ..... may be quite literally 'automatic'; elicited in an obligatory and reflexive manner under circumstances that evoke expressions of feeling'.

Finally, Kinsbourne (1971) gave intracarotid amobarbital injections to patients who had become aphasic after acute left hemisphere ischemia. He reports that after left-sided injection aphasic speech continued whereas right-sided injection resulted in complete arrest of speech and all vocalisation, suggesting that the aphasic speech was being programmed from the right hemisphere. Comprehension was preserved at all times, regardless of which hemisphere was affected by the injection.

Taken as a whole, these reports suggest that the right hemisphere, at least of split brain and hemispherectomy patients, appears to be able to process a variety of verbal inputs, both visual and auditory, although its capacity for verbal expression is very limited. It is very difficult, however, to generalise from these examples to the normal situation or to have any certainty as to exactly what is going on in any given case. Often a good deal of time has elapsed since the original trauma or operation and consequently one might expect that some compensatory adaptation in brain function might have occurred. In the case of split-brain patients some degree of bilateral speech representation may have developed as a result of early brain damage due to epileptic fits. Again, reports of individual cases are susceptible to individual differences in the brain organisation underlying cognition. The most obvious example is variation due to handedness: the relationship between handedness and cerebral dominance is far from clear (see for instance, Satz et al 1967). Later in this report it will be suggested that sex of the subject is another variable which is in some way related to the pattern of asymmetry and possibly there are others.

The present series of experiments was undertaken in order to try to discover what role the right hemisphere has in speech processing in normal, un-brain-damaged individuals: such research has the advantage of avoiding some of the difficulties involved in interpretation of data derived from the study of the brain-damaged and also affords the opportunity of looking at the functioning of the normal integrated brain, albeit in a very artificial, experimental, situation.

If it is supposed that the right hemisphere can process verbal inputs it may be asked whether this processor functions in the same way as that of the left hemisphere. If one favoured a motor theory of speech perception for the left hemisphere (Liberman et al 1967), which proposes that the processing of input is dependent upon the mechanisms which underlie output, then it could be argued that this is unlikely to provide a description of right hemisphere processing since the right hemisphere clearly has a very limited and apparently different form of output.

The following section will examine more closely some of the differences between the hemispheres in the processing of verbal inputs.

4. The speech processing abilities of the left and right hemispheres

Specialisation of the left hemisphere has been reported as far down into the perceptual processes as the detection of acoustic properties such as temporal order (Halperin et al 1973) and transition analysis (Cutting 1974).

Shankweiler & Studdert-Kennedy (1967; Studdert-Kennedy & Shankweiler 1970) found a large REA for identification of stop consonants in dichotic CV syllables. The identification of steady-state vowels, on the other hand, showed a much smaller and statistically insignificant REA (although Darwin (1971) found an REA for vowels when there was uncertainty as to what size vocal tract produced them). Liquids and semivowels (Haggard 1971) and fricatives (Darwin 1971) have also been shown to yield a right ear advantage, but of a smaller magnitude than that shown for stops (Day & Vigorito 1973; Crystal & House 1974; Cutting 1974).

Levy (1974) concluded that:

> 'there is no evidence whatsoever that the right hemisphere can analyse a spoken input into its phonetic components.... '

> '....it seems probable that the right hemisphere can decode written or spoken input by having integrated graphologies and phonologies which are tied to their appropriate meanings.... and merely utilises its few whole phonologies to translate input to meaning and meaning to output'.

Similarly, Studdert-Kennedy and Shankweiler (1970) :

> 'It seems possible that the right hemisphere's 'rudimentary comprehension' rested on auditory analysis which by repeated association with the outcome of subsequent linguistic processing, had come to control simple discriminative responses.'

> '....the auditory system common to both hemispheres is probably equipped to track formants, register temporal intervals and in general extract the auditory parameters of speech. But to the dominant hemisphere may be largely reserved the tasks of linguistic interpretation: selecting from a formant transition the relevant overlapping cues to consonantal place of articulation and to neighbouring vowel, or selecting from the infinity of temporal intervals already automatically registered in the auditory stream the one interval relevant to the perception of voicing..... Completion of such tasks is presumably pre-requisite to conscious perception of speech'.

On the other hand there is work showing that such features of speech as detection of emotional tone (Haggard & Parkinson 1971); expression of emotion through speech (Ross & Mesulam 1979) and processing of intonation contours (Blumstein & Cooper 1974) are right rather than left hemisphere functions, (although Zurif & Sait 1970 found an REA for sequences of nonsense syllables only in the presence of intonation. See Zurif & Mendelsohn 1972; Zurif 1974).

Moving on from the acoustic and phonetic analysis of the speech signal, no differences have been observed between the hemispheres at the level of meaningfulness of the verbal input (Curry & Rutherford 1967; Kimura 1967; Kimura & Folb 1968; Perera 1971) but differences have been reported at the level of word class. Curry & Rutherford (1967), for instance, found that although the difference between the ears was about the same for grammatical and for nonsense words, it was less for function words - 'the verbal materials most easily recognized and recalled'. However, since the percentage of function words correctly recalled was higher than that for the other two classes, it is possible that the smaller REA reflects a performance effect: a variation in apparent magnitude of ear advantage with overall level of performance. Thus Harshman & Krashen (1972), using data from 45 different dichotic listening experiments reported in the literature, found that a laterality coefficient based on the difference in number of correct responses on the right and on the left sides was negatively correlated with total accuracy: in other words, the higher the level of performance the smaller the apparent difference between ears. They also showed that another measure, percent of correct (POC), which measures correct scores on the right as a percentage of the total correct scores was similarly negatively correlated with accuracy. (But see Birkett 1977 who argues that the relationship between laterality and accuracy might reflect psychological processes rather than statistical bias. See also Colbourn 1978 for a critical appraisal).

A second problem with the report of Curry & Rutherford (1967) is that, since ear advantage was assessed from the number of words orally recalled, the effect of asymmetry due to input processing is confounded with that associated with making a verbal response. This is a factor which makes difficult the interpretation of much of the work carried out using the dichotic listening technique which, until recently and the introduction of manual reaction time measures, so often required either an oral response or a written response, both of which could be assumed to require left hemisphere mediation, regardless of the hemisphere processing the stimulus input.

Gazzaniga (1970) found that some split-brain patients were able to recognise 'noun-object words' in that they could match printed words to the corresponding object or picture using the right hemisphere. He concluded however that nouns derived from verbs are not represented in the right hemisphere. As for adjectives, he found that in response to pictures depicting a quality such as 'hot', 'cold' or 'round', for instance, the right hemisphere could initiate a pointing response to the appropriate printed word; it was unable to cope with adjectives such as 'shiny', 'leaky' or 'dried'. The right hemisphere was unable to mediate a response to verbs presented in the form of printed commands. These findings were confirmed by Zaidel (1976) who reported in addition some ability to process verbs. Levy & Trevarthen (1977), however, found that the right hemisphere of split-brain patients was unable to perform rhyming matches and this led these authors to conclude that:

> 'the right hemisphere can understand spoken language and perceive basic language forms but cannot generate acoustic-verbal images. It is the generative mechanisms which distinguish the hemispheres'.

Ellis & Shepherd (1974) presented concrete and abstract nouns tachistoscopically and found that words projected to the right visual field were identified more accurately overall than words projected to the left visual field. They also reported that concrete words were significantly better recognised than abstract words when they fell in the left visual field: there was no significant difference in recognition of the two words types when they occurred in the right visual field. Again, since the recognition rate for concrete words was higher than that for abstract words, the smaller field difference for concrete words could reflect a performance effect.

Hines (1976) reported a significantly larger right visual field advantage for familiar abstract nouns than for familiar concrete nouns: for unfamiliar nouns there was no significant difference in size of field advantage for the two word classes. Hines (1977), using a different word sample set, found that for high and moderate frequency words right visual field superiority, as measured by ratio scores, varied inversely with degree of concreteness. When abstract and concrete words were matched for right visual field recognition, abstract words showed a larger right visual field superiority than concrete words. These findings are consistent with suggestions that some left visual field concrete words are recognised by the right hemisphere. McFarland et al (1978) used a running memory span recognition task and found a right ear advantage for abstract words but not for concrete words when stimuli were presented dichotically opposed by speech.

Day (1977) used a manual reaction time task and visually presented stimuli and found that whereas reaction time was faster for the right visual field when stimuli were abstract nouns, there was no difference between fields for concrete nouns. He also found that the time required to recognise concrete nouns as instances of semantic categories did not differ as a function of the visual field of presentation of the nouns whereas for abstract nouns recognition as instances of semantic categories was faster when presentation was to the right visual field.

Day (1979) found a significant right visual field advantage for low imagery nouns, low imagery adjectives and for both low and high imagery verbs, but there was no visual field difference for speed of response to high imagery nouns and adjectives, suggesting that right hemisphere word recognition is related to both imageability and syntactic class.

Marshall & Holmes (1974) found no difference in the left visual field for recognition of verbs and nouns but in the right visual field a higher percentage of nouns than of verbs were correctly reported. On the other hand there was a significant frequency x field interaction with a higher percentage of high frequency than of low frequency words being recalled after presentation to the left visual field.

The last report to be considered is that of Gazzaniga & Hillyard (1971) who tested two commissurotomy patients on their right hemisphere ability to distinguish between active and passive constructions, the present and the future tense, singular and plural and also affirmative and negative. Thus for example, when a picture of a dog jumping over a fence or a picture of several dogs jumping over was presented to the left visual field the patients were required to distinguish between the spoken alternatives 'The dog jumps over the fence' and 'The dogs jump over the fence'. None of these tasks could be performed correctly except for the affirmative/negative discrimination - that this distinction could be made suggests that there was a specific deficit for the other discriminations and that the difficulty did not arise solely because of the response demands of the tasks.

In this chapter a variety of reports have been reviewed which suggest that the right hemisphere is able to decode some verbal inputs, either auditory or visual, and, to a much lesser extent, can initiate verbal utterances (spontaneous speech and some limited control of manual responses). There are suggestions for instance that the right hemisphere is able to process quite complex verbal inputs and extract sufficient information to perform what appear to be quite difficult matching tasks (Gazzaniga & Sperry

1967; Milner et al 1968) and also that in many cases comprehension appears to be intact in the absence of the left hemisphere and in the absence of propositional speech (Smith & Burklund 1966; Smith 1966; Gott 1973; Kinsbourne 1971). In contrast to this the bulk of the reports on normal subjects have found that, if the right hemisphere can process verbal inputs at all, the range of possibilities is very restricted - to nouns but not verbs (Day 1979), to concrete nouns but not abstract nouns (Ellis & Shepherd 1974; Hines 1976; Hines 1977; Day 1977; McFarland et al 1978), to familiar or high frequency words but not low frequency words (Curry & Rutherford 1967; Hines 1976, 1977; Marshall & Holmes 1974); to high image value words (Day 1979).

There appears therefore to be a discrepancy between the right hemisphere abilities observed in the brain-damaged and those which have been detected in normal, intact subjects. A possible resolution of the matter would be to conclude that the data from the brain-damaged have been misinterpreted, but this, at least as a general rule, seems most unlikely. A second answer might be that the verbal information that the right hemisphere is apparently able to process is so redundant that in fact response is made on the basis of such of the input as the right hemisphere can deal with - concrete nouns and so on. This cannot be rejected as a possibility but neither is there yet sufficient evidence to accept this solution. A third possibility is that the right hemisphere can only manifest itself when in isolation from the left hemisphere, which otherwise obscures or suppresses either its processing system or its means of expression or both, (as has been argued by Moscovitch , 1973). If this is the case then it seems most unlikely that the right hemisphere speech processing system is merely as back up system in case of left hemisphere failure but rather one might envisage that in the normal, intact brain both hemispheres co-operate in the processing of speech and it is only the limitations of our present experimental techniques which have prevented us from gaining more knowledge of the right hemisphere contribution.

5. An outline of the six experiments performed

The experiments to be described in this report are attempts to provide the right hemisphere with the conditions under which any speech processing capacity it possesses might be demonstrated. They sought both to release the right hemisphere from left hemisphere domination and also to provide the right hemisphere with a means of response (manual reaction time) which might not be as dependent on the left hemisphere as oral and written responses have been in the past.

Six experiments were carried out. The first sought to examine the relationship between magnitude of right ear advantage and amount of practice and, as in all the experiments to be described, made use of the dichotic listening technique and a manual response, the size of ear advantage being assessed from the difference in reaction time for response to stimuli at either ear. It was thought that the use of a manual response might give the right hemisphere the possibility of expressing itself independently of the left hemisphere. The second experiment was almost identical to the first but made use of equal numbers of male and female subjects, since the data collected in the first experiment suggested that there might be a sex difference in direction of ear advantage.

The third and fourth experiments examined the pattern of ear advantage across a number of recognition and recall tasks to see how the contributions of the two hemispheres differed according to the task demands.

The fifth experiment investigated the effect of concurrent verbal activity on the magnitude of ear advantage. This can be seen either as an attempt to occupy the left hemisphere and thus free the right hemisphere to act independently or, alternatively, as putting such a strain on the speech processing system that any available processing capacity, either in right or left hemisphere, must be utilised.

The sixth experiment looked at the effect of directing attention to either the right or the left ear, in order to remove any bias towards attending to the right and to examine the effect of directing attention to the left ear when it was also possible for the right hemisphere to initiate a response. In the second part of this experiment a concurrent verbal task was used in order to occupy the left hemisphere, thus, it might be thought, giving every possibly opportunity for the right hemisphere to manifest any speech processing capacity that it might possess.

1. Experiment 1: To examine the relationship between magnitude of REA and amount of practice

Introduction

A great deal of the evidence from brain-damaged patients has suggested that the right hemisphere of subjects apparently left dominant for speech can comprehend verbal inputs. The present experiment attempted to explore this possibility by looking at the effects of practice on magnitude of ear advantage in a dichotic recognition task with manual reaction time as the response measure.

Manual reaction time has two advantages over alternative forms of response to dichotic stimuli, usually measures of numbers of stimuli correctly recalled, either orally or by written response, from each ear. The first advantage is that a manual response can be programmed from either hemisphere whereas an oral or written response appears to require left hemisphere programming. Thus the dichotic listening task which has oral recall of stimuli as the measure of the distribution of verbal processing between the hemispheres confounds the effect of processing of verbal input and the effect of verbal response programming. It could be argued that REA reflects not the dominance of the left hemisphere for processing verbal input but rather left hemisphere control over the motor systems for verbal output, either oral or written. The use of manual reaction time prevents this confusion and also provides the right hemisphere with the possibility (through left hand response) of expressing itself independently of the left hemisphere.

The second advantage of manual reaction time as a response measure is that it ought not to be vulnerable to performance effects: variation in apparent magnitude of ear advantage with overall level of performance (see Chapter 1, section 4). Taking the simple, additive, reaction time model to be described here such performance effects would not be predicted, since a varying level of performance would affect all neural pathways equally, adding a constant factor to every pathway and thus resulting in a constant difference between pathways.

Two possible effects of practice could be envisaged. If the right hemisphere does in the usual case decode speech, practice might result in the response becoming 'automatic' in the Jacksonian sense ('a mindless task', as one subject put it). Alternatively, if the right hemisphere does not usually decode speech, practice might enable the 'integrated phonologies' proposed by Levy (1974) to be built up. In either case increasing involvement of the right hemisphere would be predicted, resulting in similar changes in the pattern of asymmetry with practice.

Figure 1 shows the neural pathway for each ear x hand combination before practice. It assumes that discrete finger movements (as compared with gross hand movements) are initiated by the contralateral motor cortex (Gazzaniga 1970, 1971; Brinkman & Kuypers 1972). It also adopts the model proposed by Kimura (1967) which proposes that a right ear advantage is the outcome of two factors, the first that the left hemisphere possesses superior speech processing ability to the right hemisphere and the second that contralateral inputs occlude ipsilateral inputs. Further work has suggested that with a competing right ear stimulus the left ear input arrives at the speech processor only after traversing a longer route, via the right hemisphere and the corpus callosum and that this input reaches the left hemisphere in a degraded form (see for instance Studdert-Kennedy & Shankweiler 1970). It remains unclear, however, how completely the ipsilateral inputs are occluded: there are indications that the suppression of ipsilateral inputs may be a function of the amount of spectral-temporal overlap between the competing stimuli such that the greater the degree of overlap the greater the degree of occlusion (Springer et al 1978).

The main alternative model proposed to account for the right ear advantage in dichotic listening experiments with verbal stimuli is the attentional model of Kinsbourne (1970), which will be discussed at greater length later in this report (Chapter 4, section 2), and which makes no predictions about the effect of practice on magnitude of ear advantage.

Considering first the situation before practice, the first illustration in Figure 1 shows

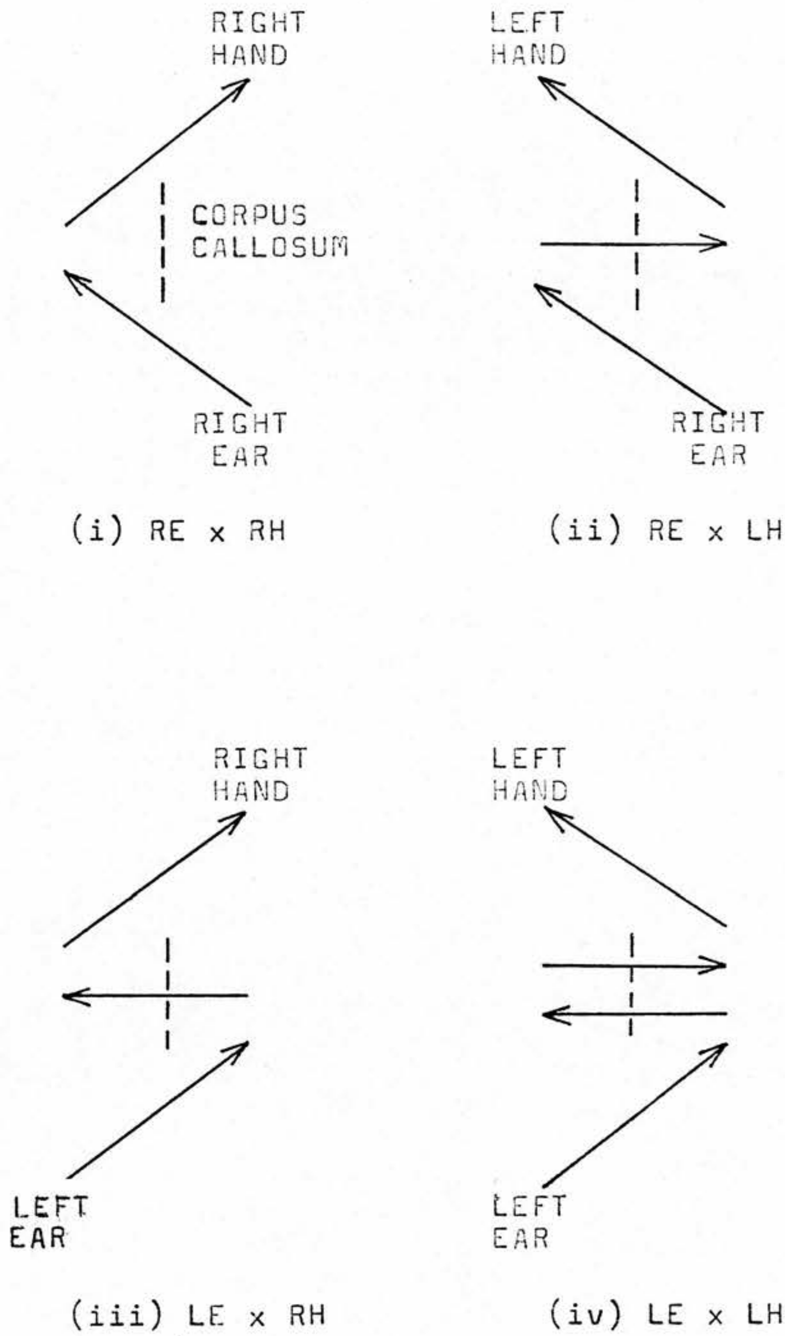


Figure 1
Illustrating the neural pathway for each ear x hand condition before practice.

the route from the left ear via left hemisphere sensory and then motor areas to the right hand (RE x RH). It was predicted that this, being the shortest pathway, would yield the fastest reaction time. In contrast to this is illustration (iv), showing the left ear to left hand pathway, (LE x LH). This is the longest pathway, and involves two crossings of the corpus callosum. It was predicted that this would yield the longest reaction times. The two remaining combinations, right ear to left hand (RE x LH) (ii), and left ear to right hand (LE x RH) (iii) appear to be comparable with each other and might be predicted to yield reaction times longer than those for the RE x RH combination but shorter than those for the LE x LH combination. Research by Umilta et al (1972) suggests that the RE x LH condition would be faster than the LE x RH condition since these authors, using manual response to tachistoscopically presented capital letters, found that verbal input information required longer to transmit than motor output information, but this (and also a report by Levy & Bowers (1974), discussed later in this section) is the only support for such an expectation: there is no theoretical reason to predict this outcome. Umilta et al also found that the RE x RH condition yielded the fastest reaction times and the LE x LH condition the slowest reaction times, although none of these field x hand interactions reached significance.

It would be predicted that as, with practice, the right hemisphere intervened, reaction times to the

LE x LH combination would become significantly shorter, since both crossings of the corpus callosum would be eliminated. It might be predicted also that reaction time to the LE x RH combination would become shorter, although not to such a great extent, since the nature of the information crossing the corpus callosum would be changed from verbal input to motor output. It was predicted that reaction times to left ear inputs, and in particular to inputs linked with a left hand response, would decrease significantly over time by comparison to reaction times to right ear inputs.

There is a major assumption underlying these predictions, namely that verbal processing carried out by the right hemisphere will take place at a rate comparable to that of the left hemisphere. If it processes more slowly then either (i) the response mediated by the left hemisphere will be produced before that initiated by the right hemisphere and so the pattern of reaction times will not change with practice or (ii) the right hemisphere will initiate responses, but the slower reaction times will be indistinguishable from the slower reaction times, resulting from longer pathways, before practice, so again there will be no change observed. There are good reasons for supposing that right hemisphere processing of verbal inputs would proceed at the same rate as left hemisphere processing: (i) right hemisphere processing of non-verbal inputs is carried out at rates comparable to that of the left hemisphere. For instance, Kallman (1978) found a mean manual reaction time for speech (CV syllables) of 627 msec for the right ear and 671 msec for the left ear. For music (the note 'A', 440 Hz) a mean of 698 msec for the right ear and 677 msec for the left ear. Rizzolatti et al (1971) found a RVF advantage for letter recognition (single capital letters), mean reaction time for the RVF was 431.5 msec and for the LVF was 450.0 msec. He found a LVF advantage for face recognition, with a mean reaction time for the RVF of 610.0 msec and for the LVF of 594.5 msec. There was no field x hand interaction. (Incidentally, Klatsky & Atkinson (1971) regard recognition of capital letters as a spatial task and find a LVF advantage in a manual reaction time task. The whole area is full of traps for the unwary).

Geffen et al (1971) found a LVF advantage for manual response in a face recognition task, with a mean reaction time of 429 msec for the LVF compared with 454 msec for the RVF. Obviously no real comparison can be made between processing rates in these experiments, since right and left hemisphere tasks cannot be equated for difficulty. All that can be said is that the right hemisphere is not conspicuously slower than the left hemisphere.

Filbey and Gazzaniga (1969) obtained a LVF mean of 341.0 msec and a RVF mean of 336.0 msec for manual response to the presence or absence of a dot (in contrast to a significant 33 msec RVF advantage when verbal rather than manual response was required, this possibly indicated that it was the need for a verbal response which led to the significant right field advantage). Bradshaw & Perriment (1970) examined manual reaction time to onset of a light in either the right or the left visual field and found a LVF mean of about 427 msec and a RVF mean of about 441 msec (these figures are estimates from the graph given in their report). The LVF advantage was significant. The last two reports mentioned both assume that stimulus detection was carried out by the contralateral hemisphere, so that reaction times reflect processing within the contralateral hemisphere. Processing rates for the two hemispheres thus appear comparable and at least do not suggest slower processing in the right hemisphere.

If it is assumed that right hemisphere speech processing involves some general right hemisphere processing ability rather than a specialised right hemisphere speech processor, then the processing rates for speech stimuli should be comparable to those for non-speech stimuli. The obvious reply to this is that the right hemisphere processor may indeed be able to decode speech, but it is a relatively more difficult task for this processor than for the left hemisphere processor, and this will be reflected in reaction time. Indeed it could be argued that it is a difference in processing efficiency between the hemispheres rather than trans-callosal crossing time which underlies the finding of a right ear advantage or a right visual field advantage for verbal material in these reaction time studies. The experimental evidence does not as yet indicate which of these explanations is the correct one.

(ii) If in the intact individual the two hemispheres work in conjunction with one another then, assuming that the right hemisphere participates in speech processing, it would be strange if its processing rate were slower than that of the left hemisphere - if it were, then the outcome of its processing would be useless, since the left hemisphere would already be processing something else. On the other hand, if the right hemisphere speech analyser is some kind of primitive, vestigial process, manifesting itself only in brain-damaged individuals, then its processing could be slower.

Turning now to work which has been done by other authors using reaction time to dichotic stimuli, Springer (1971) used a dichotic listening task and manual reaction time to the target CV 'da', and found an REA averaging 50 msec. There was no significant hand or hand x ear effect. Kallman (1978), in the work referred to earlier, found an REA of similar magnitude and no hand x ear interaction.

Levy & Bowers (1974) using the target stimulus 'two' and manual reaction time found a significant REA of 131 msec (when calculated from the data for 40 trials) or 86 msec when calculated from the data for the last 20 trials, which the authors considered better to reflect asymptotic performance. Again the hand and hand x ear effects were not significant although, over all trials, the trend was towards fastest reaction times in the RE x RH condition and slowest in the LE x LH condition with the RE x LH combination being slower than RE x RH and faster than LE x RH - in other words, the same pattern that was observed by Umilta et al. When the data were considered in two parts, each of 20 trials, reaction times to right ear stimuli decreased significantly in the second part compared with the first (572.1 vs 469.3 msec) while that for the left ear also decreased (673.4 vs 632.4 msec) but not significantly. However, since the total duration of 20 trials was only 3 mins 20 secs, it seems unlikely that these effects reflect the processes being examined here which could be assumed to take place over a longer time. In the experiment to be described subjects were tested for 34 mins 40 secs plus rest pauses on each of two consecutive days.

Perl & Haggard (1975) also used a similar paradigm, but required the verbal response 'da' to the stimulus 'aye'. They used 13 female subjects and, in view of the results of experiments that will be described later in this report, it is interesting to note that they failed to find a significant REA overall. However, inspection of the block by block data for each subject shows very little consistency in direction of ear advantage for any given subject across blocks, which suggests that this particular test is not a reliable measure of ear advantage. In the two experiments reported here in which reaction times across blocks could be inspected subjects showed a much higher degree of consistency and there was a significant test-retest correlation. Perl & Haggard found a significant ears x blocks interaction (4 blocks of 200 trials were used): responses to target stimuli were faster in the later blocks when the right ear was stimulated, compared with the left ear. A significant REA of 34 msec was obtained for the last block. Again this trend is in the opposite direction to that predicted according to the model being proposed here but again 200 trials only occupied 200 seconds, so by the beginning of the fourth block only 10 minutes of testing and 9 minutes of rest pauses had elapsed. The fact that the required response was verbal makes this experiment quite unlike that to be reported here.

The present experiment, then, was designed to test the prediction that improvement in manual reaction time with practice in a dichotic recognition task would be significantly greater for response to left ear inputs than for response to right ear inputs and that, in particular, a considerable improvement in performance for the LE x LH condition would be observed relative to all other conditions.

Method

Subjects

Subjects were 24 staff and students of the University of Edinburgh, 7 male and 17 female. They were all self-classified right-handers with no known left-handed relatives. Research by the present author

(Perera 1971) and by others (Ettlinger et al 1955; Satz et al 1967) has shown that although a person may regard himself as right-handed, the existence of a left-handed relative is often associated with LEA. Ettlinger et al discuss a case report of a patient who regarded himself as right-handed (but who was in fact partly ambidextrous according to the criteria adopted to define manual laterality in that study), who became markedly dysphasic following right temporal lobectomy, and they report that one of his sisters was left-handed (except for writing). They reviewed fifteen earlier cases of aphasia in right-handed patients with right-sided lesions reported in the literature and found that in nine instances familial sinistrality was present. This evidence alone would not support the statement that the presence of familial sinistrality is in any way predictive of right hemisphere dominance for speech since it could be the case that just as many individuals displaying left hemisphere dominance for speech also have left-handed relatives. This matter is clarified by Perera and by Satz et al. Perera found that all five self-classified right-handers showing LEA on a dichotic listening task had left-handed relatives whereas of the remaining fifteen right-handed subjects showing REA only one had a left-handed relative. Satz et al, using a larger sample (123 subjects), found that the incidence of familial sinistrality was nearly twice as great in those subjects who showed speech representation on the same side as the (test-classified) dominant hand: left brain, right hand = 27%; right brain, left hand = 33%; left brain, left hand = 57%; right brain, right hand = 56%. There is thus a high probability that right-handers with left-handed relatives will be right hemisphere dominant for speech.

Subjects were also without known speech or hearing impediment and had English as their first language.

Preparation of stimulus tape

A dichotic tape was produced using DITMA (Dichotic Tape Making Apparatus) a system developed at Edinburgh University. This equipment is capable of synchronising onsets on the two channels to within 5 msec.

Thirty blocks of fifteen pairs of words were constructed. Of these words six: Lion, Full, Branch, Sail, End and Spider, were target words to which the subjects had to respond, and they were embedded randomly in a matrix of twenty-four other words, none of which was repeated, in each block. Thus in each block of fifteen pairs of words were six pairs containing a target word. Target words could occur randomly at either ear and also simultaneously on both ears, however the latter condition was not included in the analysis. The full tape thus contained 30 x 6 = 180 pairs of which one element was a target stimulus and ninety of these target words occurred on the left and ninety on the right. When the six pairs of stimuli were eliminated in which both words in the pair were target stimuli the figures were reduced to eighty four target stimuli to each ear.

Four seconds elapsed between onset of one pair of words and onset of the next pair and fourteen seconds between the onset of the last item of one block and the onset of the first item of the next block. The whole tape, comprising thirty blocks of stimuli, was divided into two equal sections of fifteen blocks, each with forty-two presentations of the target stimuli to each ear. The duration of a fifteen block section was 17 minutes 20 seconds.

In the production of this tape using DITMA a certain amount of noise was produced between one item and the next, since the procedure involves the stopping and starting of tape recorders. This noise could have either or both of two possible effects. The first is that a click could engage some non-speech processor which could in some way interfere with subsequent speech processing. The second possibility is that any noise could create an attentional bias favouring the right hemisphere. In order to avoid either of these possibilities all this noise was spliced out of the tape.

Procedure

Subjects received the following written instructions:

When you put on the headphones you will hear a series of words. These will be in pairs, that is, two different words will be played simultaneously, one to each ear. The words will be presented in sets of fifteen pairs with a pause between each set.

Each of the six words listed below will appear once in each set of fifteen pairs. When you hear one of these listed words, press the key as soon as possible.

The first two sets will be examples and will give you a chance to practice. For these two sets you may refer to the printed list of words below, but try to memorise the words as the list will be removed after the first two sets.

LION

FULL

BRANCH

SAIL

END

SPIDER

Half of the subjects were instructed to respond with the left index finger throughout the experiment and the other half to respond with the right index finger. Pressing the response key stopped a timer (Advanced SC-1 Decatron timer) which had been triggered, through a voice key, by the onset of the target word. The reaction time was recorded; reaction times exceeding 1,999 msec were discarded.

Subjects heard the tape through Canal E-102 Stereo headphones. Headphone orientation (with corresponding channel) was counterbalanced between subjects. The tape was played on a Cambridge Pye 9137 recorder at a comfortable listening level.

The order of presentation of the stimuli was controlled, half of the subjects receiving blocks 1-15 (Session 1) and then blocks 16-30 (Session 2), with a two minute rest pause between, and the other half receiving blocks 16-30 (Session 1) followed, again after two minutes, by blocks 1-15 (Session 2). Two additional practice blocks were given immediately before the first session.

Subjects heard the whole tape twice, once on each of two consecutive days. This provided a total of four comparable reaction time samples (four test sessions), two from each day, so that comparisons could be made between reaction times for the two ears at various stages of practice. Subjects were told at the end of the first day's sessions that they would have to perform the same task the following day and were asked to rehearse the six words in the meantime.

Results

1. The mean reaction times for each ear and each session are given below in Table 1. The mean reaction times and standard deviations for each subject are given in Appendix 1.1 and 1.2. The data from Table 1 were plotted and are shown on Figure 2.

An analysis of variance examining reaction time across sessions for the two ears for each of the response conditions (right hand/left hand) failed to disclose any significant difference between reaction times for the two hands ($F(1,22) = 0.5$, n.s.); between

Table 1

Mean reaction times (msec) for each ear for each of the four test sessions. (N = 12 for each entry)

	Left Hand		Right Hand	
	Left Ear	Right Ear	Left Ear	Right Ear
Session 1	974.8	935.8	972.4	965.8
Session 2	931.2	923.0	1003.2	976.1
Session 3	915.6	885.1	968.9	950.6
Session 4	928.7	902.7	980.8	972.2

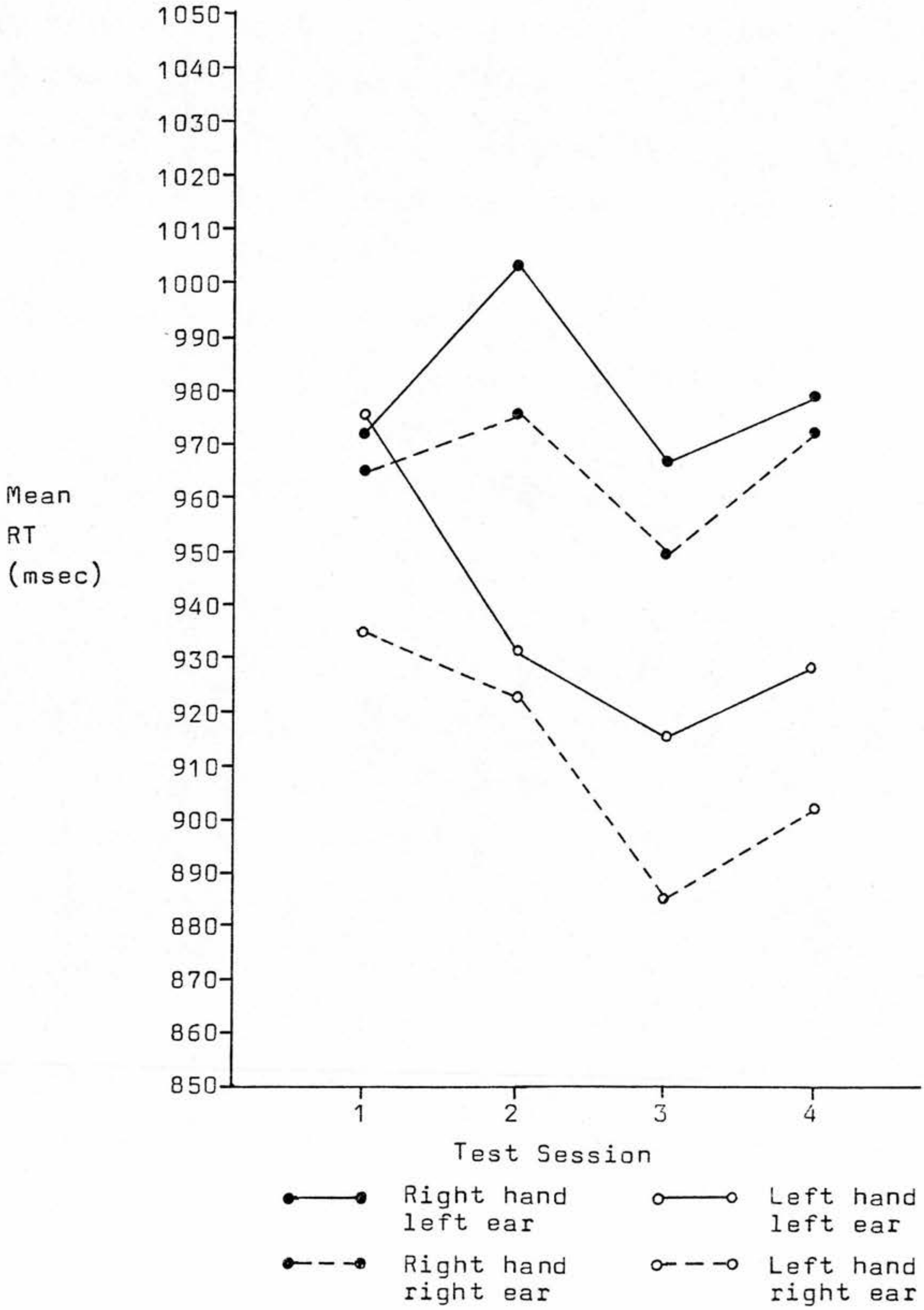
Table 2

Mean reaction times (msec) for male (N=7) and female (N=17) subjects, pooled across all four test sessions.

	Left Ear	Right Ear
Male	966.8	915.9
Female	956.4	948.4

Figure 2

Mean reaction times (msec) for each ear for each of the four test sessions. (N = 12 for each point)



ears ($F(1,22) = 1.6$, n.s.) or between practice sessions ($F(3,66) = 1.3$, n.s.). There were no significant interactions between any of the variables. The complete analysis of variance summary table is given in Appendix 1.3.

2. Examination of Table 2 and Figure 2 shows that the trend was towards faster reaction times for the left hand than for the right hand over all ear and practice conditions.

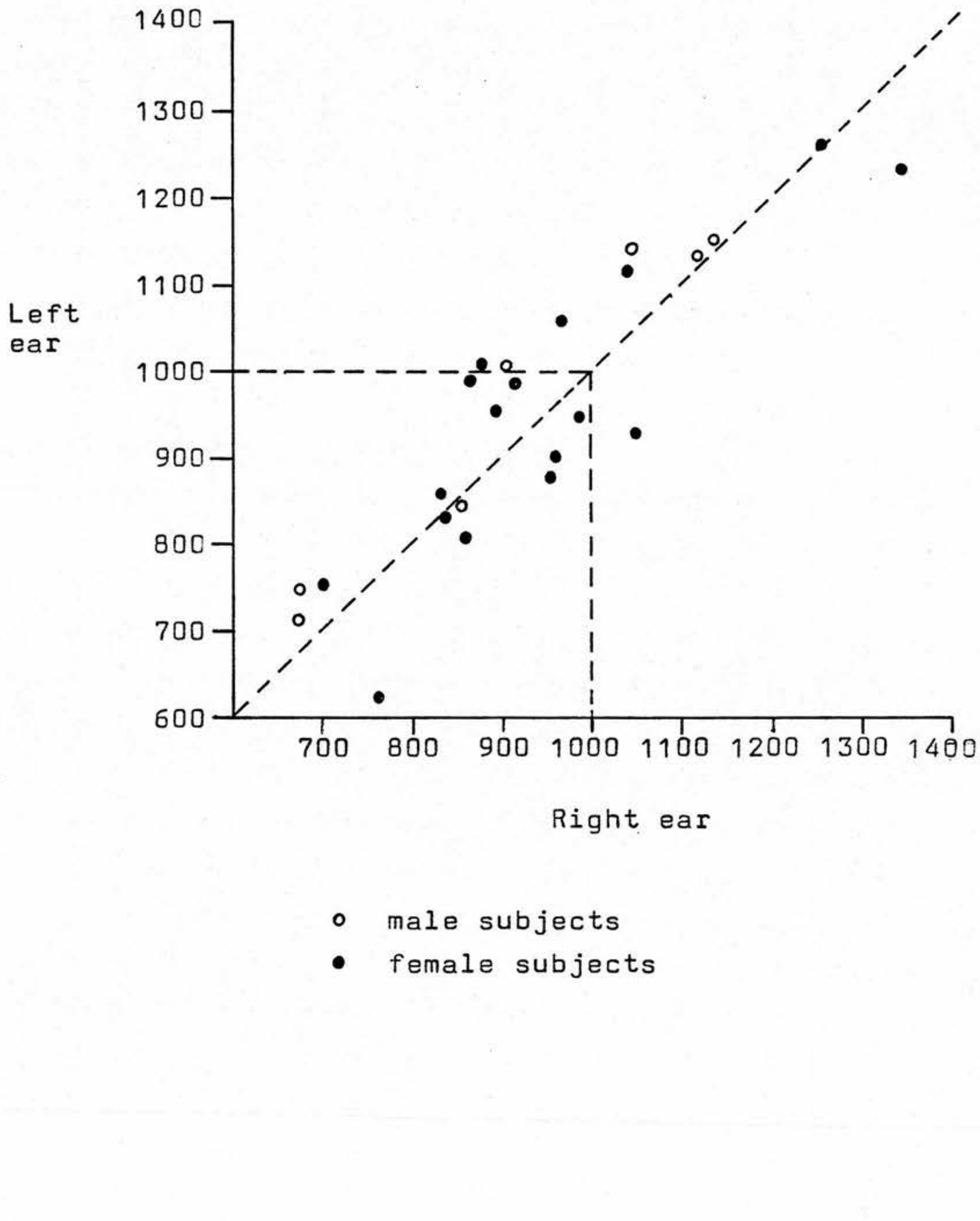
3. Examination of the mean reaction time for each ear and for each subject pooled over all four sessions (Figure 3) revealed that of the 17 female subjects 8 showed a left ear advantage (i.e. mean reaction time to left ear input was faster than mean reaction time to right ear input) and one was borderline (showing a right ear advantage of 1.4 msec). Of the 7 male subjects only one showed a left ear advantage and this was only small (7.7 msec). An analysis of variance performed on the mean reaction time data pooled across all four sessions and examining two variables, sex of subject and ear to which target stimulus was presented (Table 2) yielded a nonsignificant ear effect ($F(1,22) = 2.88$, n.s.) favouring the right ear, and a nonsignificant sex x ear interaction ($F(1,22) = 1.53$, n.s.). The summary table for this analysis is given in Appendix 1.4.

Discussion

The hypothesis being tested was that the decrease in latency of reaction time with practice would

Figure 3

Mean reaction time (msec) for each ear for each subject pooled over all four sessions.



be greater for response to left ear inputs than for response to right ear inputs and that this difference would be particularly marked in the LE x LH condition by comparison with any other condition. It is impossible to examine the data for this effect because of the absence of a significant right ear advantage.

There are several possible reasons that could be put forward to account for the absence of a significant right ear advantage. One is that the experimental apparatus might have been unsatisfactory, for instance that the stimulus tape was deficient and was not a reliable measure of REA. This might have arisen if the dichotic pairs were not accurately synchronised. Alternatively the voice keys or the timer could have been unreliable. Examination of the data given in Appendix 1.1, showing the mean reaction times for individual subjects across sessions suggests that these are unlikely sources of error. There is very little variability in direction of ear advantage for any given subject: most subjects showing REA showed it in all four sessions and six of the nine subjects showing a left ear advantage for the pooled data showed it in at least three sessions. The test-retest correlation was calculated, comparing magnitude of ear advantage over the first two sessions with magnitude of ear advantage over the final two sessions. The Pearson product-moment correlation coefficient, r, was .79, ($t = 6.106$, df 22, $p<.001$), showing that there was a high degree of consistency between scores in the two halves of the experiment, i.e. that the test was a reliable measure. Similarly, if unreliable voice keys or timer were responsible for the absence of REA a smaller test-retest correlation would have been predicted.

Another possible source of error could have been some systematic difference between the two channels. Headphone orientation (with corresponding channel on the tape) was counterbalanced between subjects but not according to sex of subject, since this was not considered to be a relevant variable, and neither was it counterbalanced within subjects. Thus for half of the subjects Channel 1 was presented to the left ear and Channel 2 to the right ear and for the other half of the subjects Channel 1 was presented to the right ear and Channel 2 to the left ear. It was thus at least possible that, for instance, all the male subjects were tested with one headphone orientation and many of the females with the opposite orientation and that some difference between the channels, for instance loudness or level of noise, was responsible for the apparent difference between sexes in direction of ear advantage. The data were checked for this possibility. An analysis of variance revealed no main effect of ear ($F(1,22) = 1.57$ n.s.) and also no main effect of headphone orientation ($F(1,22) = 0.22$ n.s.) and no interaction between ear to which stimuli were presented and headphone orientation ($F(1,22) = 2.2 \times 10^{-4}$ n.s.).

It thus appears that the apparent difference between the sexes in direction of ear advantage is not due to any systematic difference between the two channels and the interaction of this with headphone orientation.

If the experimental equipment is eliminated as a possible source of error, one other possible explanation of the failure to demonstrate a significant right ear advantage remains, and this lies in the high proportion of female subjects in this experiment who showed a left ear advantage: perhaps there is a real difference between the sexes in cerebral asymmetry for this task. Such differences have apparently been found for other tasks, and existing evidence for sex differences in cognitive processing and cerebral asymmetry will be discussed in Chapter 3. In the present case, however, the obvious reply to any argument in favour of a difference in cerebral asymmetry between the sexes is that there was a higher percentage of females than males in the sample and that on top of that the sample size was very small. The only answer to that is to select another and larger sample, with equal numbers of male and female subjects. The next experiment to be described is very similar to the one already discussed and the predictions concerning the improvement in reaction time to right and left ear inputs with practice are the same. This time however equal numbers of male and female subjects were used, in order to ascertain whether a significant right ear advantage could be obtained using this tape and experimental equipment and whether direction of ear advantage in this experiment does vary according to the sex of the subject.

2. Experiment 2: To examine the relationship between magnitude of REA and amount of practice and to investigate sex differences in direction of ear advantage

Method

Subjects

Subjects were 24 males and 24 females, staff and students of the University of Edinburgh. They were all self-classified right-handers with no known left-handed relatives, had no known hearing deficit and had English as their first language.

Preparation of stimulus tapes

The stimulus material used was essentially the same as that described for Experiment 1; however certain changes were made. Items which had caused difficulty to subjects in Experiment 1 were removed as were the six pairs of words in which target stimuli had been presented simultaneously to both ears. The new tape was thus slightly shorter and comprised 24 rather than 30 blocks of words. The full 24 block tape was divided as in Experiment 1 into two comparable parts, this time of 12 blocks each and the duration of a 12 block session was 13 minutes 50 seconds. Each target word occurred randomly and equally often at either ear within each of the two 12 block sessions. There were thus 36 presentations of target stimuli to each ear in each session.

Procedure

Subjects were given the same written instructions as in Experiment 1. 12 of the male subjects and 12 of the female subjects responded with the left index finger throughout the experiment and the other 12 subjects of each sex responded with the right index finger. Reaction times exceeding 1,999 msec were discarded.

Headphone orientation was counterbalanced between subjects within the two sex groupings.

The order of presentation of stimuli was controlled, with half the subjects within each sex grouping receiving blocks 1-12 (Session 1) followed by blocks 13-24 (Session 2), with a two minute rest pause between, and the other subjects receiving blocks 13-24 (Session 1) followed, after a two minute rest pause, by blocks 1-12 (Session 2). Two practice blocks were given immediately before the first session.

As in Experiment 1 each subject heard the whole tape twice, but unlike the earlier experiment, where testing was spread over two days, all the test sessions were on the same day, with only two-minute rest pauses between Sessions 1 and 2 and between Sessions 3 and 4 and 5 minutes between Sessions 2 and 3. This modification was introduced because subjects showed strong fatigue effects in Experiment 1, as the upswing for Session 4 on Figure 2 shows, which outweighed the usefulness of prolonging the experiment. In all other respects the procedure adopted here was the same as that of Experiment 1.

Results

1. The mean reaction times for each ear and for each session are given in Table 3. Figure 4(a) shows the difference in reaction time between ears for the two response conditions (right hand, left hand). Figure 4(b) shows the difference between ears combining the data for the two hands. These data are plotted separately for males and for females in Figures 5 and 6.

Mean reaction times and standard deviations for individual subjects are given in Appendix 2.1 and 2.2.

An analysis of variance was carried out on the data, examining the effect of sex of subject, ear to which the target stimulus was presented, hand used to make the response and amount of practice. There was a significant difference between ears ($F(1,44) = 7.1$, $.05>p>.01$) and a significant ear x practice interaction ($F(3,132) = 3.7$, $.05>p>.01$). The main effects of sex, hand and practice and all other interactions failed to reach significance. The summary table for this analysis is given in Appendix 2.3.

2. Investigation of the ear x practice interaction revealed a significant difference between ears for Sessions 1, 3 and 4 ($F(1,176) = 10.2$, 7.0 and 6.8 respectively, $.01>p>.001$) but not for Session 2 ($F(1,176) = 0.1$, n.s.). This is shown clearly in Figure 4(b). A summary of the analysis is given in Appendix 2.4.

Table 3

Mean reaction times (msec) for each of the four practice sessions.
Right hand = right hand used to make response; left hand = left hand used to make response.

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
Male subjects/ right hand (N=12)	939.7	890.9	858.5	856.4	914.6	858.9	905.4	847.1
Male subjects/ left hand (N=12)	928.0	887.6	895.9	877.8	893.1	851.1	928.3	860.8
Female subjects/ right hand (N=12)	928.7	894.4	930.9	925.5	931.5	920.6	927.0	922.3
Female subjects/ left hand (N=12)	912.4	878.7	864.9	871.8	876.1	854.7	879.1	880.9

Table 3 (contd)

Mean reaction times (msec) for each of the four practice sessions.
Right hand = right hand used to make response; left hand = left hand used to make response.

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
Male subjects, pooled over hands (N=24)	933.8	889.2	877.2	867.1	903.8	855.0	916.8	853.9
Female subjects, pooled over hands (N=24)	920.6	886.6	897.9	898.6	903.8	887.7	903.1	901.6
All subjects: right hand (N=24)	934.2	892.6	894.7	890.9	923.1	889.8	916.2	884.7
All subjects: left hand (N=24)	920.2	883.2	880.4	874.8	884.6	852.9	903.7	870.8
All subjects, pooled over hands (N=48)	927.2	887.9	887.5	882.9	903.8	871.3	909.9	877.8

Figure 4

Mean reaction time (msec) for each ear x hand condition for each of the four test sessions. (N = 24 for each point)

Mean reaction time (msec) for each ear in each of the four test sessions.

(N = 48 for each point)

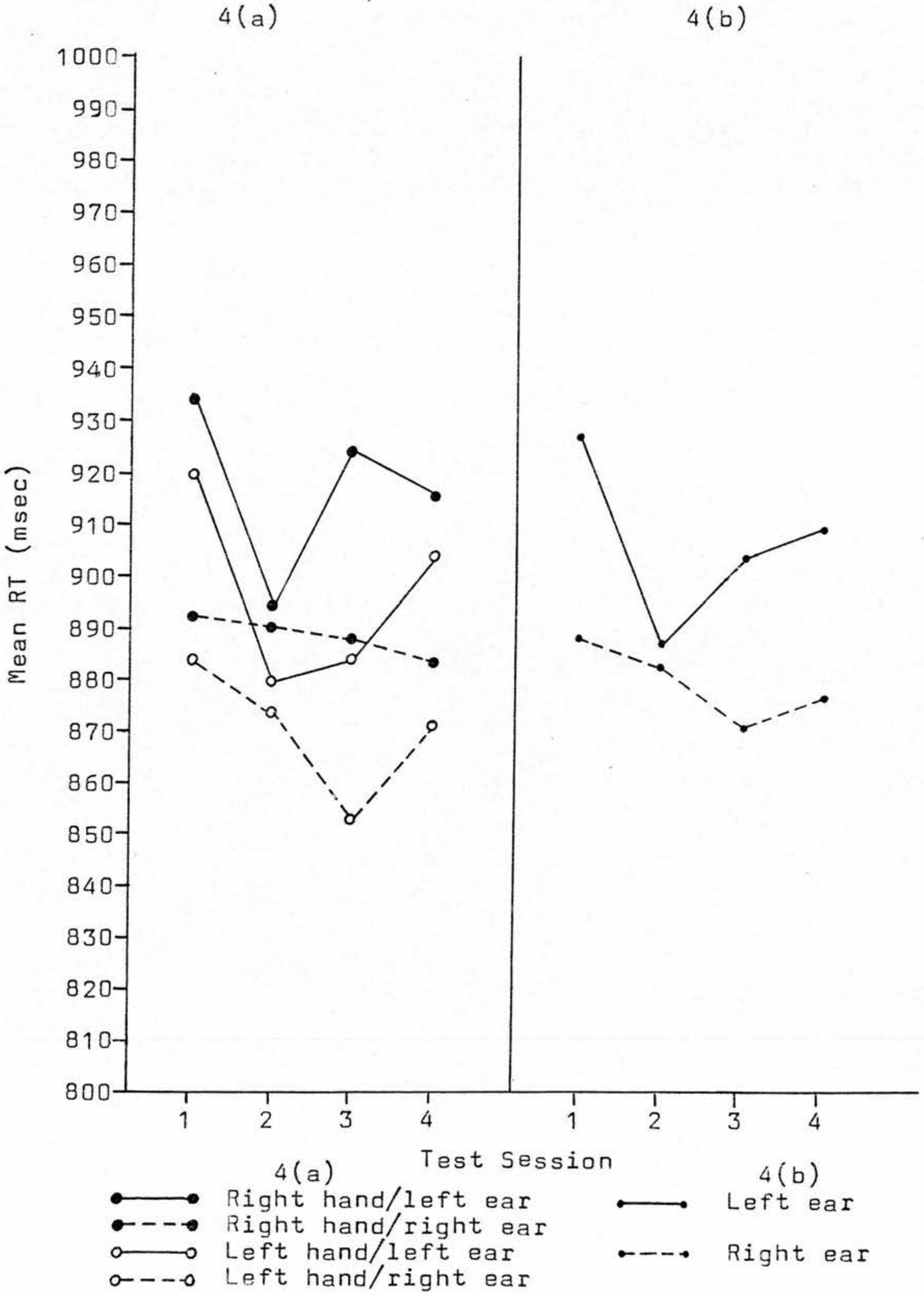


Figure 5

Mean reaction time (msec) for each ear x hand condition (a) for male subjects, (b) for female subjects. (N= 12 for each point)

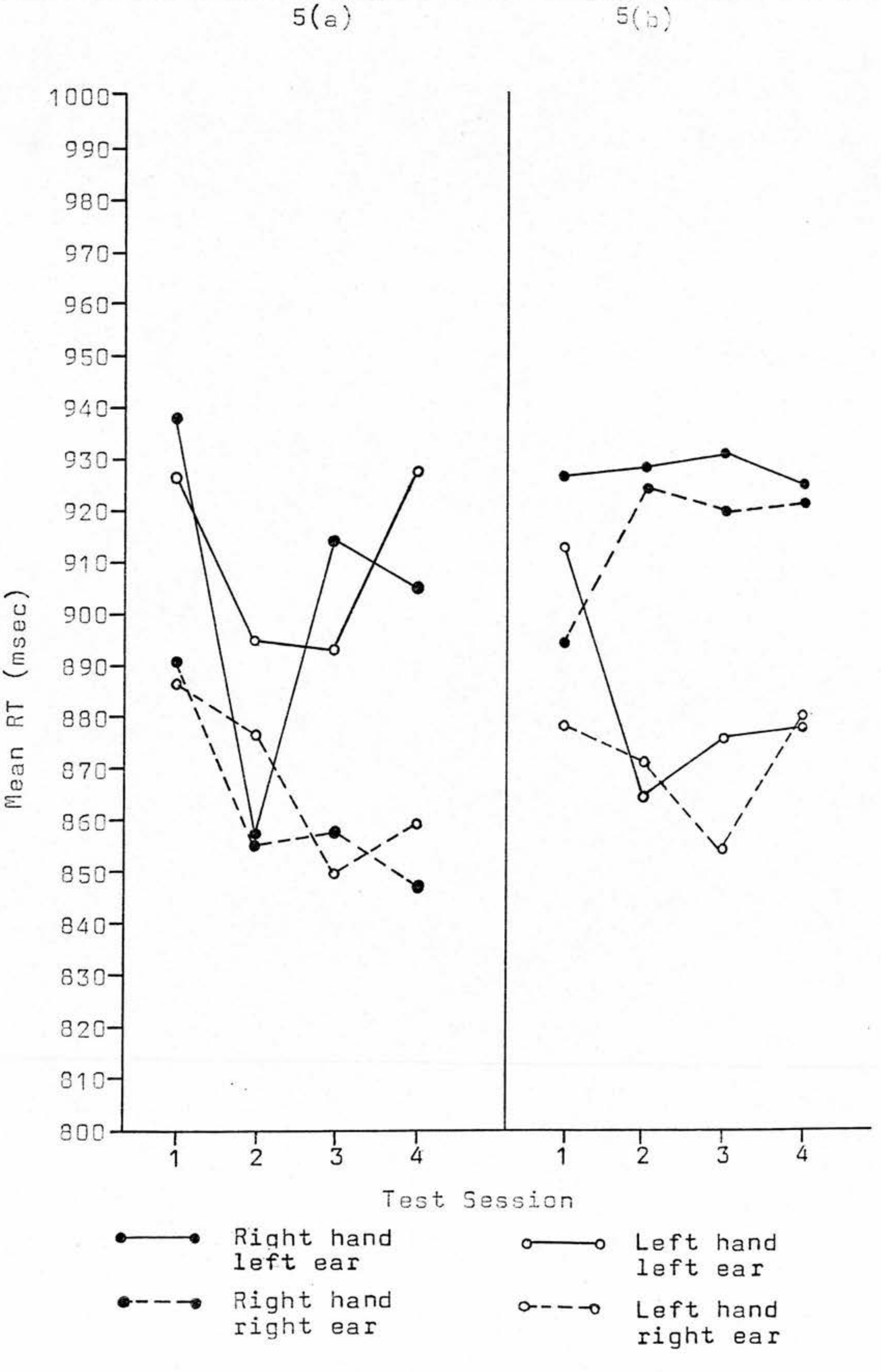
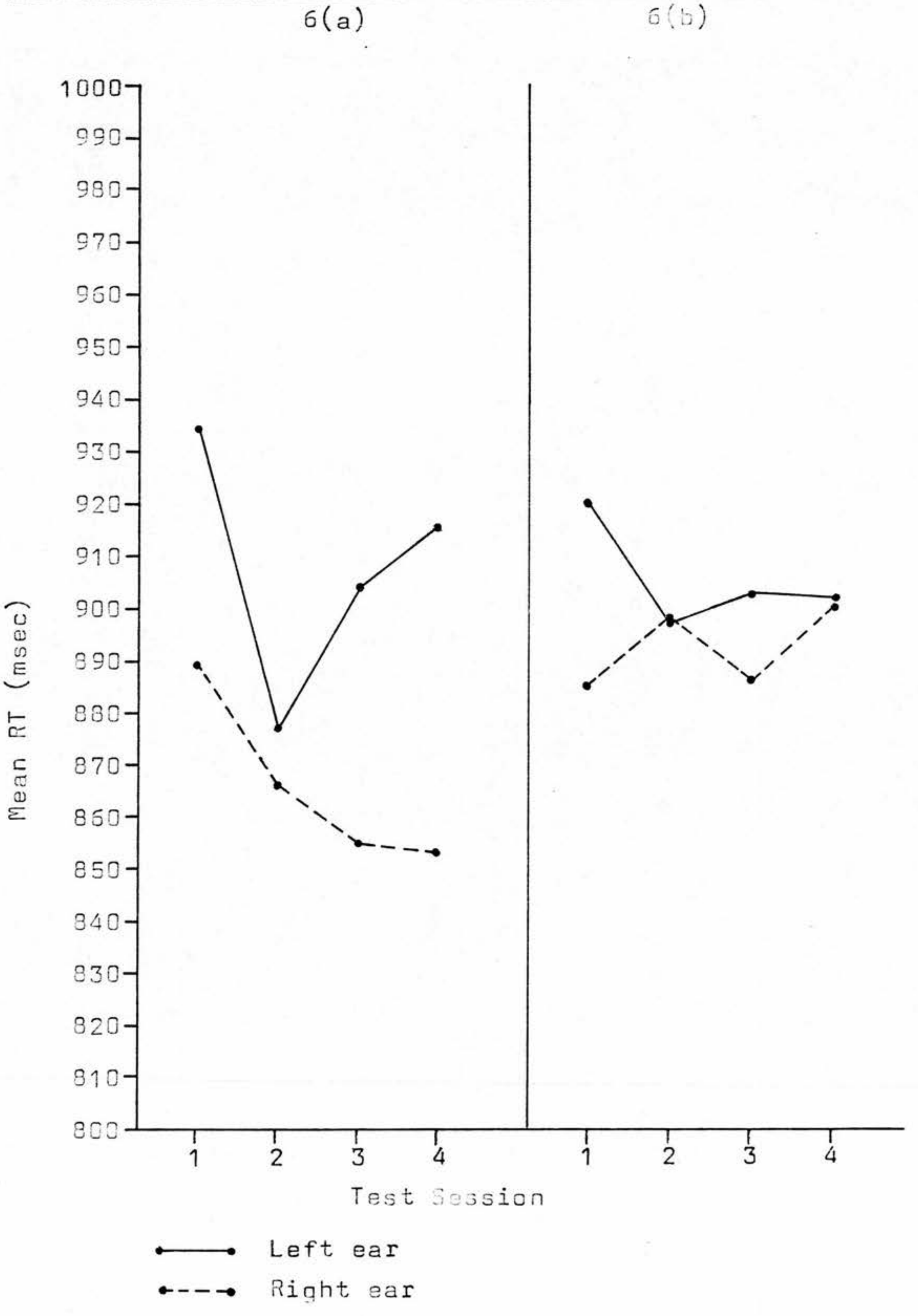


Figure 6

Mean reaction time (msec) for each ear in each test session (a) for male subjects, (b) for female subjects. (N= 24 for each point)



3. Data were subjected to a logarithmic transformation. Such a transformation is appropriate for reaction time data where a positively skewed distribution of scores could be expected. This arises because at one end of the distribution there is a limit, i.e. reaction times can be no faster, whereas at the other end there is no limit (except for an arbitrary cut-off at 1,999 msec). Visual inspection of random samples of data did suggest such a skewed distribution.

Mean reaction times for the transformed data are given in Table 4. The data are plotted on Figure 7, which shows the pattern of reaction time for the two ears for each of the four conditions, Figure 7(a) showing the reaction time for the two hands separately and Figure 7(b) showing the data pooled for the two hands. If Figure 7 is compared with Figure 4, which plots the corresponding untransformed data, it will be seen that the shapes of the graphs are almost identical.

The summary table for the analysis of variance of the log. transformed data is given in Appendix 2.5. The pattern of results is very similar to that derived from the untransformed data. The difference between ears reached significance ($F(1,44) = 7.38$, $.01>p>.001$). The ear x practice effect did not reach significance but the sex x ear x practice interaction was significant ($F(3,132) = 3.33$, $.05>p>.01$).

Figures 8 and 9 separate out the reaction times for male and female subjects and are comparable

Table 4

Mean reaction times ($\log_{10}$) for each of the four practice sessions.

Right hand = right hand used to make response; left hand = left hand used to make response.

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
Male subjects/ right hand (N=12)	2.9495	2.9255	2.9139	2.9082	2.9401	2.9103	2.9357	2.9070
Male subjects/ left hand (N=12)	2.9375	2.9225	2.9271	2.9126	2.9241	2.8990	2.9403	2.9039
Female subjects/ right hand (N=12)	2.9453	2.9290	2.9489	2.9448	2.9485	2.9435	2.9468	2.9445
Female subjects/ left hand (N=12)	2.9352	2.9155	2.9136	2.9131	2.9191	2.9080	2.9209	2.9201

Table 4 (contd)

Mean reaction times ($\log_{10}$) for each of the four practice sessions.

Right hand = right hand used to make response; left hand = left hand used to make response.

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
Male subjects, pooled over hands (N=24)	2.9435	2.9240	2.9205	2.9104	2.9321	2.9047	2.9380	2.9054
Female subjects, pooled over hands (N=24)	2.9402	2.9222	2.9313	2.9290	2.9338	2.9258	2.9339	2.9323
All subjects: right hand (N=24)	2.9474	2.9272	2.9314	2.9265	2.9443	2.9269	2.9413	2.9257
All subjects: left hand (N=24)	2.9363	2.9190	2.9204	2.9128	2.9216	2.9035	2.9306	2.9120
All subjects, pooled over hands (N=48)	2.9419	2.9231	2.9259	2.9197	2.9329	2.9152	2.9360	2.9189

Figure 7

log. transformed data: mean reaction times for each ear x hand condition for each test session. (N = 24 for each point)

log. transformed data: mean reaction time for each ear for each test session. (N = 48 for each point)

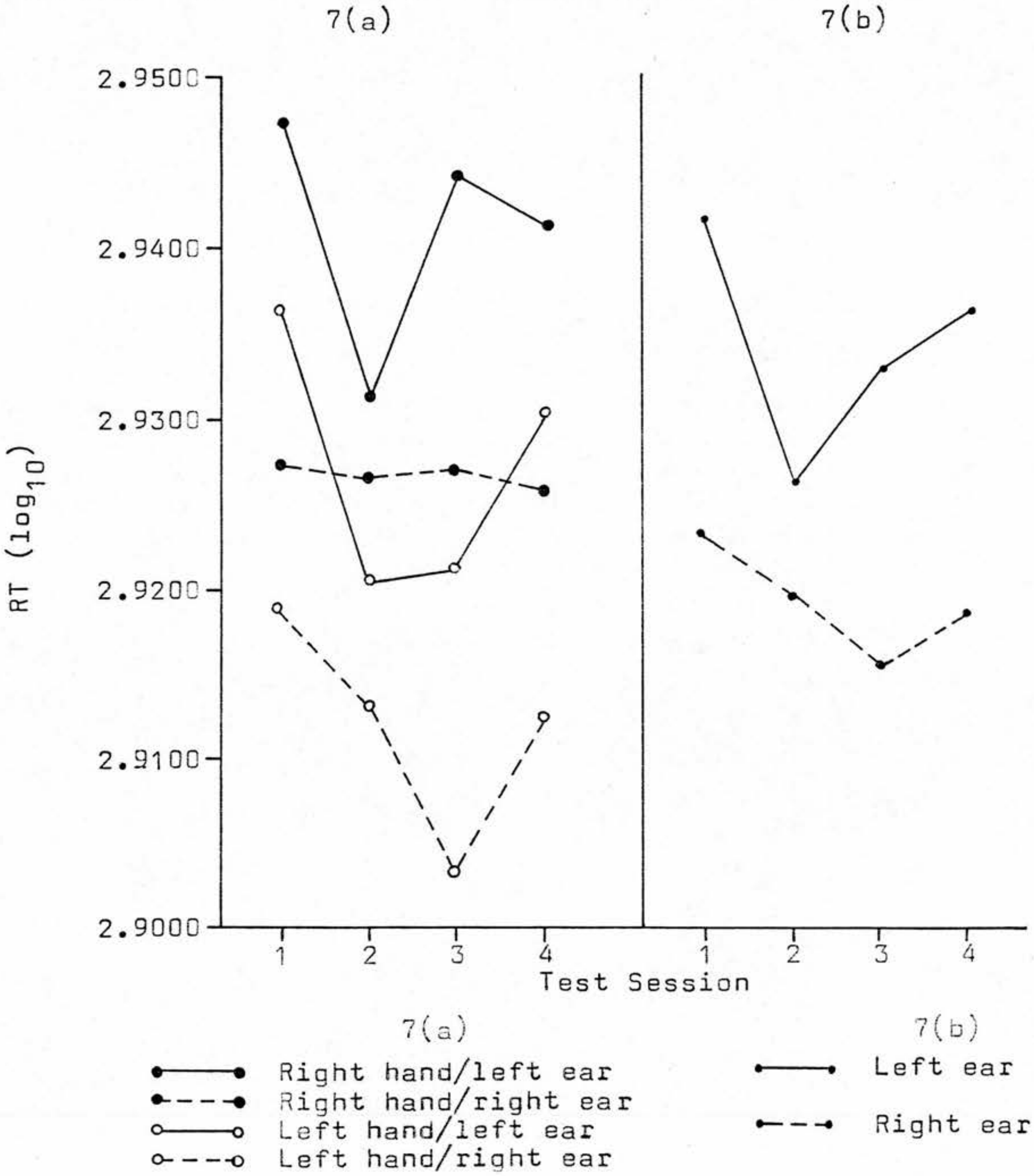


Figure 8

log. transformed data: mean reaction time for each ear x hand condition (a) for male subjects, (b) for female subjects.
(N = 12 for each point)

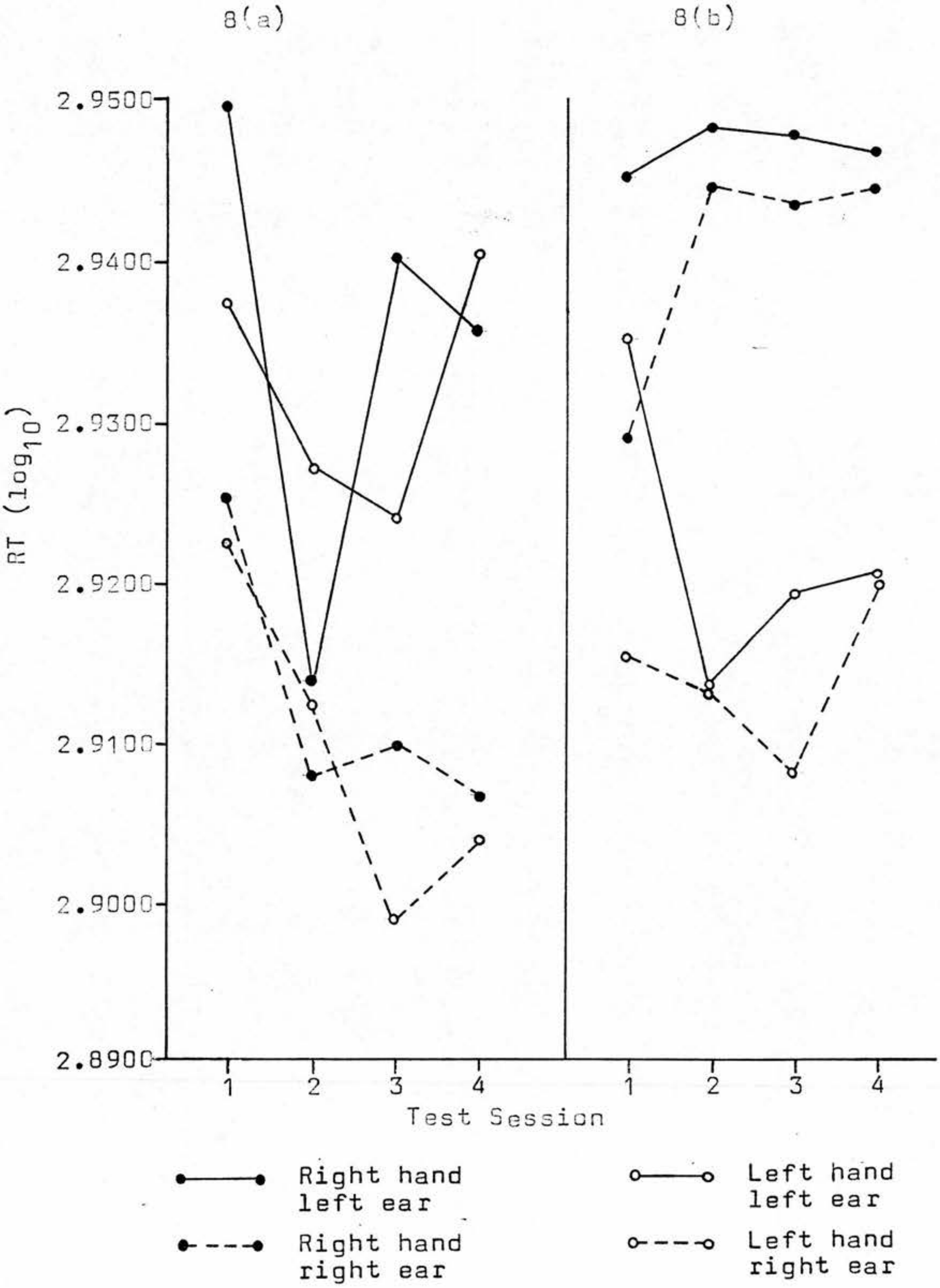
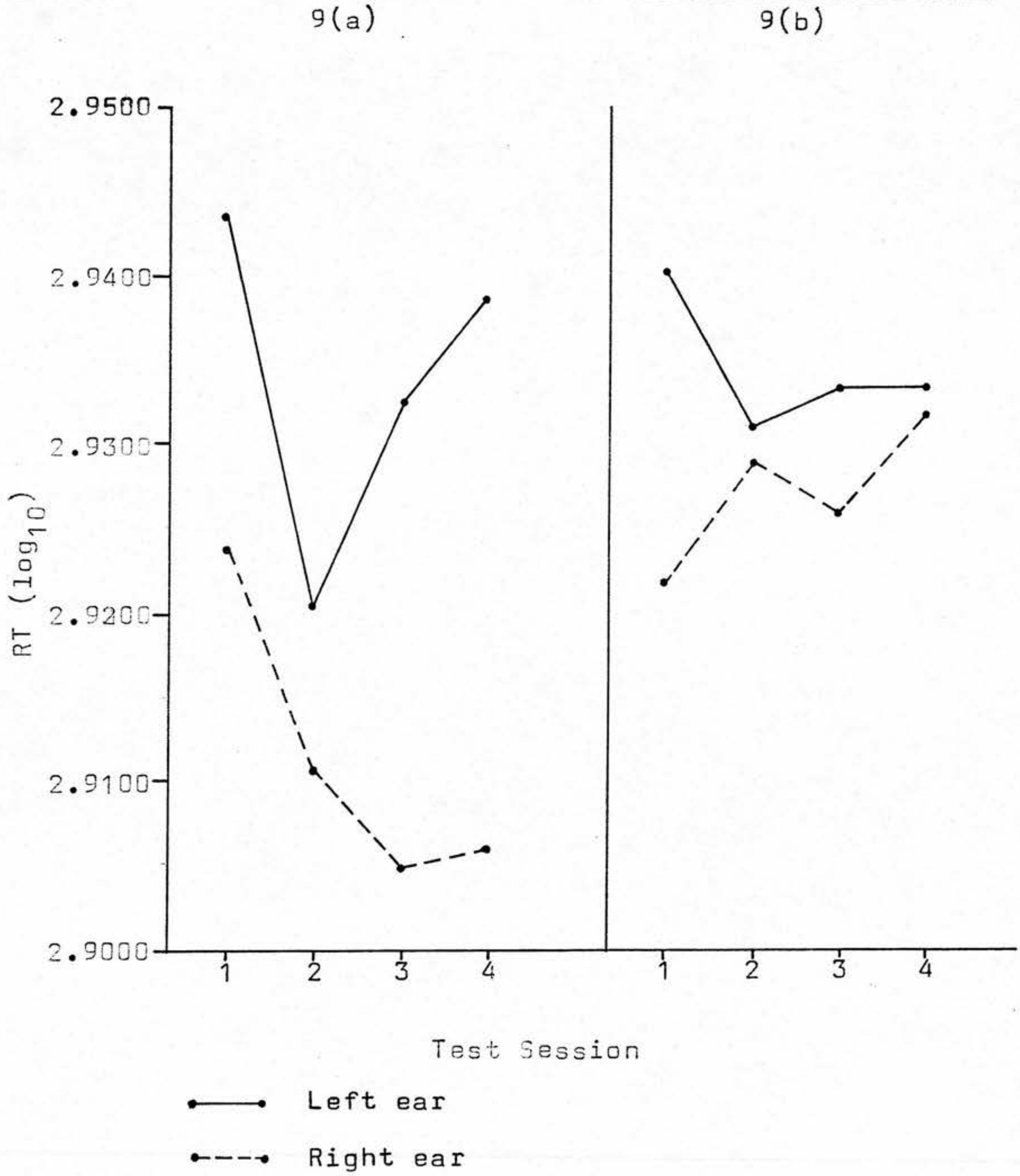


Figure 9

log. transformed data: mean reaction time for each ear in each test session (a) for male subjects, (b) for female subjects.
(N = 24 for each point)



to Figures 5 and 6 (untransformed data). An analysis of the sex x ear x practice interaction (see Appendix 2.6), which examines the difference between ears at each stage of practice for the male subjects and for the female subjects, as illustrated in Figure 9, shows that whereas both male subjects and female subjects show a significant difference in reaction time for the two ears in Session 1 and no significant difference between ears in Session 2, only male subjects show a significant difference between ears in Sessions 3 and 4.

4. Observation of the data for individual subjects showed that 6 of the 24 male subjects showed LEA in two or more sessions, compared with 13 of the female subjects. Data for the 11 female subjects showing REA and the 13 female subjects showing LEA were analysed separately. Mean reaction times are given on Table 5 and these data are plotted on Figures 10 and 11.

An analysis of variance was performed examining the speed of reaction time for the two female groups; whether response to material presented to one ear was faster than response to material presented to the other; the difference in speed of response for the right and the left hand; the effect of practice and all inter-

Table 5

Data for female subjects showing reaction time (msec) for each session for subjects showing REA (N=11) and subjects showing LEA (N=13).

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
Subjects showing REA								
Right hand response	932.3	827.0	939.4	873.2	947.4	825.6	923.9	831.9
Left hand response	901.9	796.1	809.8	772.8	822.9	740.4	810.1	781.2
Mean of pooled hand data	915.8	810.2	868.7	818.4	879.5	779.1	861.9	804.2
Subjects showing LEA								
Right hand response	926.1	942.6	924.8	962.8	920.1	988.5	929.1	986.9
Left hand response	922.9	961.3	920.0	970.7	929.3	969.1	948.1	980.6
Mean of pooled hand data	924.6	951.2	922.6	966.5	924.4	979.6	937.9	984.0

Figure 10

Female subjects only.
Mean reaction time (msec) for each hand x ear condition for each test session: (a) for subjects showing a left ear advantage (N = 13), (b) for subjects showing a right ear advantage (N = 11).

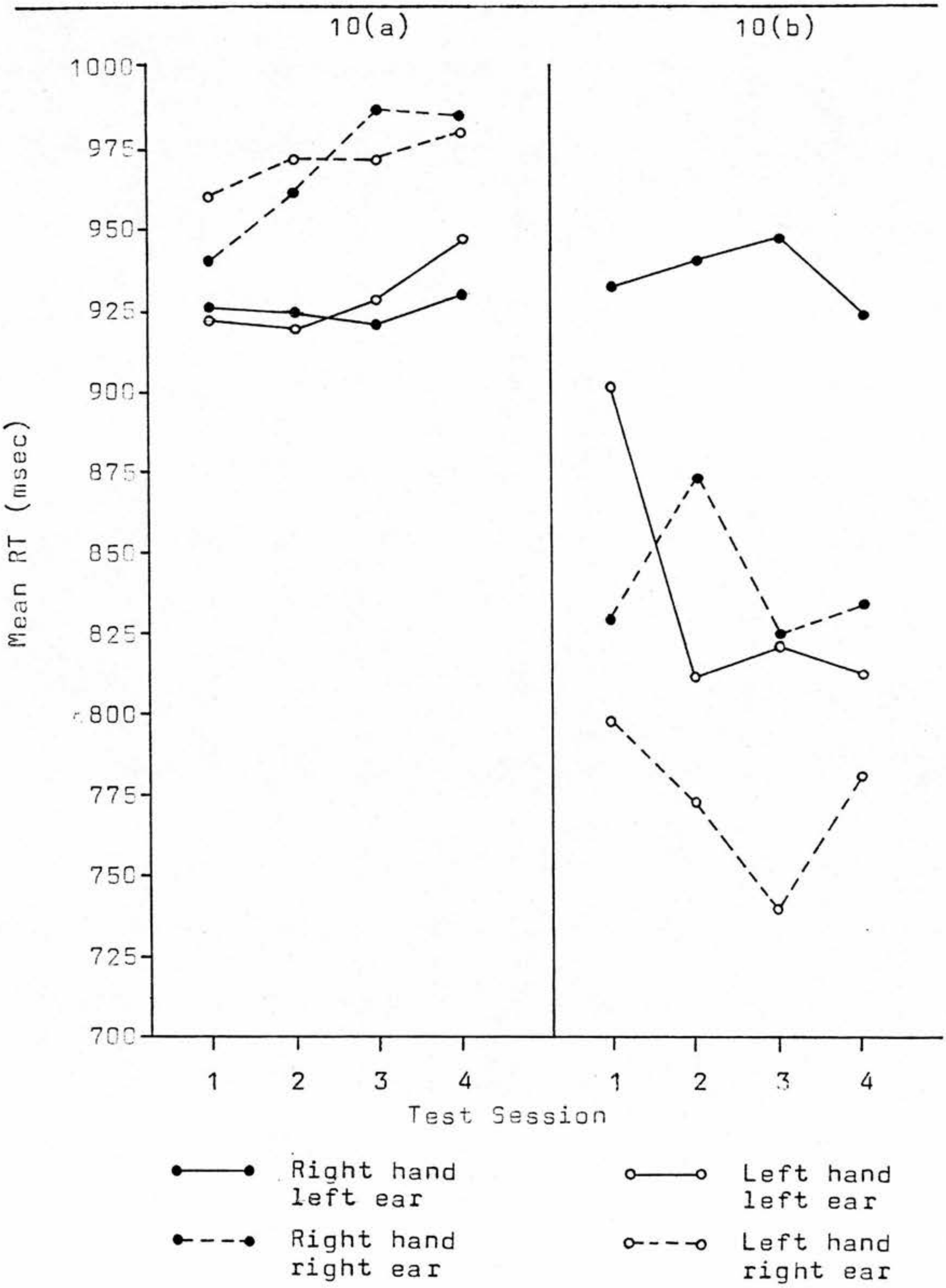
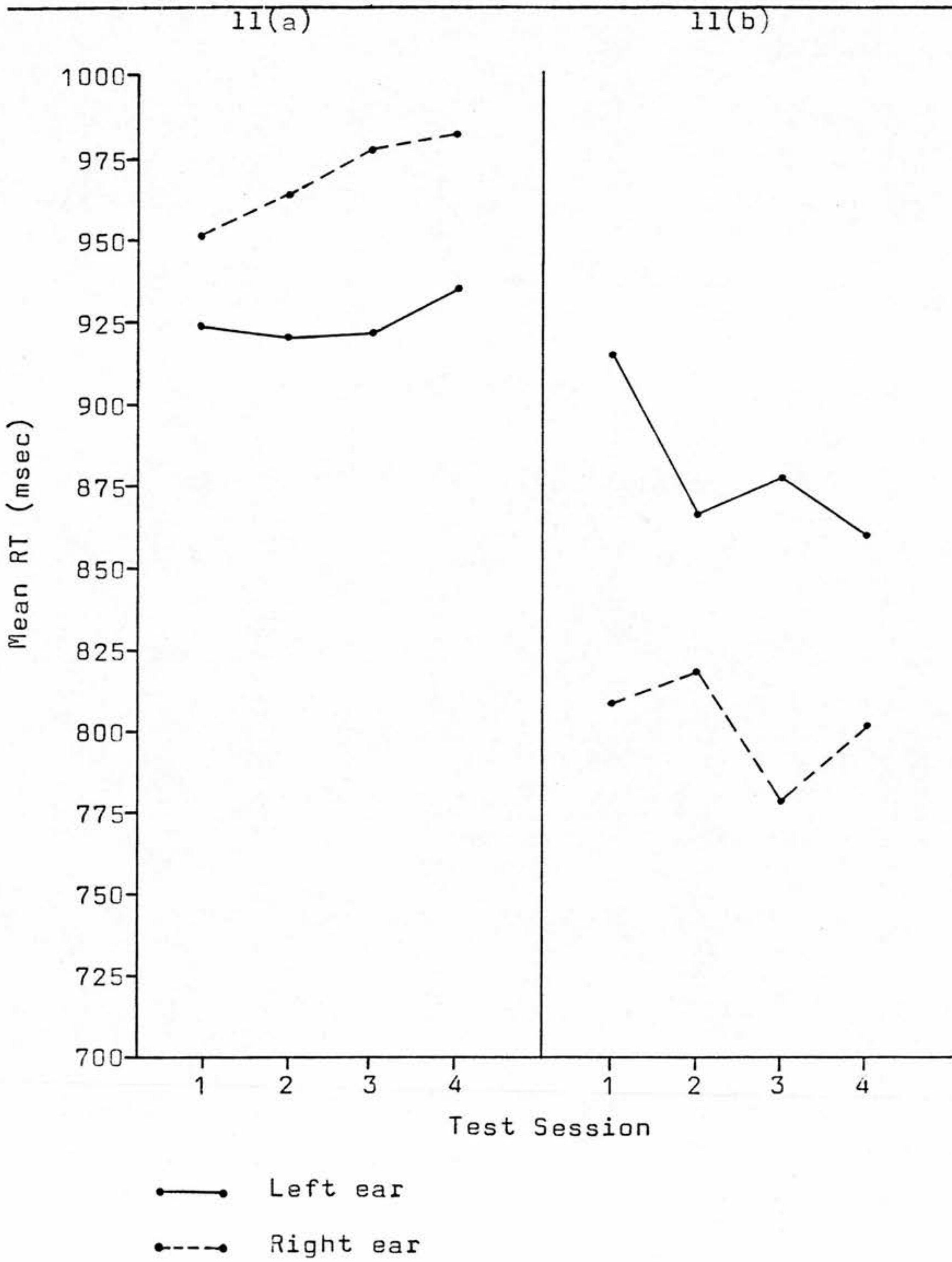


Figure 11

Female subjects only.
Mean reaction time (msec) for each ear in each of the four test sessions: (a) for subjects showing a left ear advantage (N = 13), (b) for subjects showing a right ear advantage (N = 11).



actions between these variables. The summary table for this analysis is given in Appendix 2.7.

The analysis revealed a significant difference in overall reaction time between those subjects showing REA and those subjects showing LEA ($F(1,20) = 6.50$, $.05>p>.01$) and a significant interaction between direction of ear advantage (REA/LEA) and ear (right/left), ($F(1,20) = 34.51$, $p<.001$). The latter might be expected since the REA/LEA groups were selected on the basis of direction of ear advantage. However, a full analysis of this interaction revealed that the two groups did not differ significantly with respect to left ear reaction time ($F(1,40) = 1.1$, n.s.) but only differed significantly in right ear reaction time ($F(1,40) = 15.1$, $p<.001$). The data involved in this interaction are given on Table 6, and a summary of this analysis is given in Appendix 2.8. The difference in speed of reaction time between the ears was significant for both groups of subjects, those showing REA ($p<.001$) and those showing LEA ($.01>p>.001$).

In summary, left ear performance for subjects showing REA and for subjects showing LEA did not differ significantly. However right ear performance for subjects showing REA was significantly better than right ear performance of subjects showing LEA.

5. The test-retest correlation was calculated, comparing magnitude of ear advantage (L-R) for the first two sessions with the magnitude of ear advantage for the final two sessions. The correlation coefficient,

Table 6

Mean RT (msec) for right and left ears for female subjects showing REA (N=11) and female subjects showing LEA (N=13).

	Left Ear	Right Ear
REA	881.5	803.0
LEA	927.4	970.3

r, for all subjects was .68 ($t = 6.18$, df 46, $p<.001$). For females alone the correlation was .76 ($t = 5.47$, df 22, $p<.001$) and for males alone .59 ($t = 3.43$, df 22, $.01>p>.001$).

6. Mean reaction times were calculated for each of the six target stimuli. Data are given in Table 7 and illustrated in the form of a histogram on Figure 12.

Table 7 shows the mean reaction time pooled over all four sessions for each of the six target words for each hand x sex condition. Corresponding standard deviations are given in Appendix 2.9 together with details of mean performance level for each word. This shows, for instance, that presentation of the word 'Spider' elicited a response on 99.3% of occasions, averaged over all conditions, whereas the word 'Branch' was less often correctly recognised, with a performance level of 92.2%. The differences appear to be quite stable across all four sex x hand conditions.

An analysis of variance was performed on the data summarised in Table 7, examining effects of sex of subject; target word; hand used for response and ear to which target stimulus was presented. A significant difference was found between mean reaction times for the six words ($F(5,220) = 171.2$, $p<.001$) and between ears, with faster RTs for the right ear ($F(1,44) = 7.4$, $.01>p>.001$). A significant word x ear interaction was also found ($F(5,220) = 3.2$, $.01>p>.001$). No other main effects or interactions reached significance. A summary table of this analysis is given in Appendix 2.10.

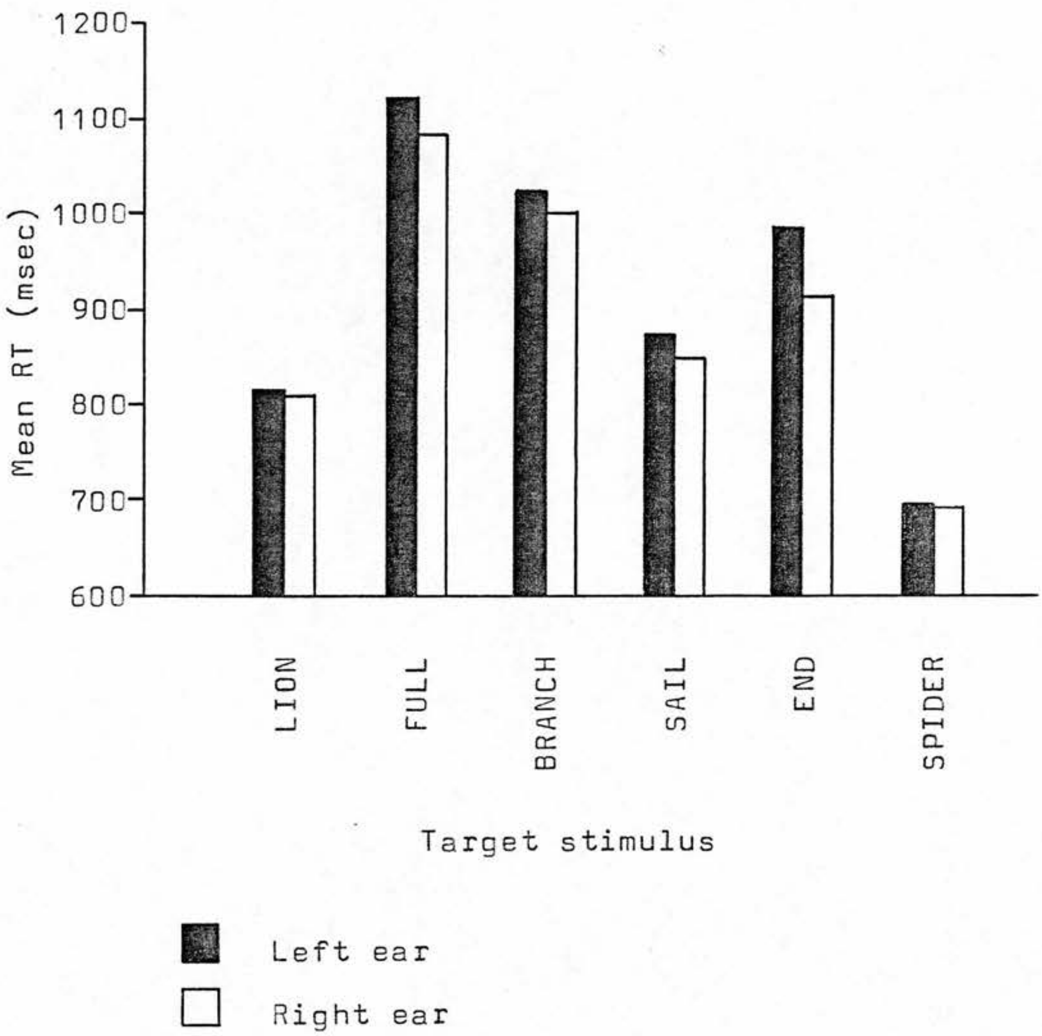
Table 7

Mean reaction time (msec) over all four sessions for each of the six target words. (Each entry is based on the data for 12 subjects)

	Male Subjects				Female Subjects			
	Right Hand Response		Left Hand Response		Right Hand Response		Left Hand Response	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
LION	809.9	791.2	836.8	800.7	825.1	849.4	796.0	796.1
FULL	1063.8	1038.4	1167.2	1103.9	1167.6	1113.6	1081.3	1074.9
BRANCH	1028.0	976.1	1039.1	1003.5	1018.1	987.0	1018.2	1041.3
SAIL	882.2	843.0	853.8	828.9	921.9	901.9	853.4	831.1
END	1008.3	918.5	1016.8	905.1	1004.5	954.4	925.7	882.5
SPIDER	696.6	681.6	673.5	675.2	724.7	731.7	687.6	683.0

Figure 12

Mean reaction times for the two ears for each of the six target stimuli. (N = 48)



LION - at least 50 per million
FULL - 100 or over per million*
BRANCH - 100 or over per million**
SAIL - 100 or over per million**
END - 100 or over per million*
SPIDER - 24 per million

* 500 words occurring most frequently
** 500 words occurring next most frequently

(Thorndike and Lorge 1944)

A Tukey test was performed to compare mean reaction time for the six words. The mean reaction times were as follows:

Lion = 813.2 msec
Full = 1101.3 msec
Branch = 1013.9 msec
Sail = 864.5 msec
End = 952.0 msec
Spider = 694.2 msec

For the difference in reaction time between any two words to be significant at the .05 level, the difference must equal at least 45.08 msec. Applying this to the reaction times above, all comparisons achieve significance.

It will be seen from the figures given above and from the histogram in Figure 12 that reaction times to the words 'Lion' and 'Spider' are shorter than reaction times to the words 'Full', 'Branch','Sail' and 'End'. This difference clearly does not relate to the word length, for instance, the word 'End' does not elicit faster RTs than the word 'Spider'. It is however possible that the distinctive 'Sp' is sufficient to elicit fast RTs.

The differences in reaction time between words do not relate to the frequency of (written) usage, at least as measured by the Thorndike-Lorge word count.

'Full' and 'End' are among the 500 words occurring most frequently, and 'Branch' and 'Sail' are among the 500 words occurring next most frequently. Neither 'Lion' nor 'Spider' are included in this group of the 1000 most frequently occurring words. 'Full', 'Branch', 'Sail' and 'End' all occur at least 100 times per million words, whereas 'Lion' occurs only with a frequency of at least 50 per million and 'Spider' only at 24 per million. In other words, the two stimuli eliciting fastest reaction times occur less often in written English than do the stimuli eliciting slower reaction times.

It is possible that this distribution of reaction times reflects primacy and recency effects, with 'Lion' the first word on the list given to subjects and 'Spider' the last word on the list. There is no way of testing this with the data available since all subjects were presented with the target words listed in the same order.

Further analysis of the significant word x ear interaction showed that, although there was a significant right ear advantage over all words, only the difference between ears for the word 'Full' ($.05 > p > .01$) and for the word 'End' ($p < .001$) reached significance. The summary table for this analysis is given in Appendix 2.11.

Summary of the main results

1. An analysis of variance revealed a significant difference between ears and a significant ear x practice interaction. The main effects of sex, hand and practice and all other interactions failed to reach significance.

2. Investigation of the ear x practice interaction revealed a significant difference between ears in Sessions 1, 3 and 4 but not in Session 2.

3. Data were subjected to a logarithmic transformation. This gave a pattern of results very similar to that obtained from the untransformed data except that there was a significant sex x ear x practice interaction rather than simply an ear x practice interaction. When this was analysed further it was found that both male subjects and female subjects showed a significant REA in Session 1 and no ear advantage in Session 2, but only male subjects showed a significant difference between ears in Sessions 3 and 4.

4. Just over half of the female subjects showed LEA rather than REA. When data for the female subjects were analysed separately it was found that while right ear performance was significantly better in subjects showing REA than in subjects showing LEA, left ear performance did not differ significantly between the two groups.

5. A significant test-retest correlation was obtained.

6. There were significant differences in reaction time to the six target stimuli.

Discussion

Two hypotheses were being tested in this investigation. The first that practice would significantly improve left ear performance by comparison with right ear performance, and the second that significantly more females than males would show LEA.

The first hypothesis has been verified to a limited extent, but to such a limited extent as to make interpretation difficult. The hypothesis was verified in so far as in Session 1 the two ears differed significantly while in Session 2 they did not, left ear improvement being greater than right ear improvement. The hypothesis was not verified in that significant right ear advantage re-appeared in Sessions 3 and 4. It could be argued that the differences in direction of ear advantage between male subjects and female subjects have swamped the predicted effects. However, although the female subjects form a relatively heterogeneous group, the male subjects do not, and it is these 24 male subjects and not the female subjects who show a significant REA in Sessions 3 and 4.

Differences in reaction time between the two hands were also fundamental to the original predictions, and the absence of any significant difference between reaction time for the two hands adds further difficulty to the interpretation of the data.

The second hypothesis has also been verified to a certain extent. A higher percentage of females than of males showed LEA, but this effect did not reach significance. This does not mean that this is not in fact a reliable effect, rather that the number of females who show LEA as a percentage of the whole group is not sufficient to achieve significance. That this trend towards LEA in females has been demonstrated with two separate randomly selected samples of subjects suggests that the result is reliable.

Considering the female group only, the main finding was that there was no significant difference in left ear performance between subjects showing REA and subjects showing LEA. Since, in subjects showing LEA, it is assumed that the right hemisphere is processing input, it could be argued that the right hemisphere is also processing left ear input in subjects showing REA and that the right hemisphere to left hemisphere callosal pathway is not activated. This must remain as a possibility and cannot be pursued any further on the data available.

If subjects showing LEA merely had the functions of the two hemispheres somehow switched round then it might be predicted that left ear performance for these subjects would be comparable to right ear performance in subjects showing REA. This was not the case. Clearly, also, whatever processing mechanism these LEA subjects are using is less efficient than that of the REA subjects and hence results in longer reaction times.

Several questions arise from this. Is the direction of ear advantage a fixed quality, in other words, does a given subject showing REA in a certain experiment show REA in all comparable experiments? What is a comparable experiment? What are the task requirements which necessitate left hemisphere processing? Could a subject showing REA in one experiment involving speech processing show LEA in another experiment also involving speech processing?

These questions are of particular interest since in an earlier experiment using a dichotic recall task Perera (1971) found that of 16 right-handed females with no known left-handed relatives only one showed LEA and that only marginally. This is in striking contrast to the results of the present experiment. If this difference in outcome between the two experiments were reliable it would suggest not that the recognition task described here required, of necessity, a different form of processing from the recall task (in which case all subjects should perform in a certain way on one task and in a different way on the other task) but rather that the recognition task <u>could in some subjects</u> involve a different form of processing - hence the variability in direction of ear advantage among females in the present recognition task. From the results of the present experiment it appears that this 'choice' of hemisphere is not available to male subjects, or at least that they do not exercise this choice within the context of this experiment, since so few of them show LEA.

It also appears that subjects who did use the right hemisphere for this task performed relatively inefficiently, inasmuch as their reaction times were comparatively slow.

This is perhaps analogous to the findings discussed by Levy & Trevarthen (1976) in their paper on metacontrol (a term which refers to the neural mechanisms that these authors suggest might determine which hemisphere will attempt to control cognitive operations). Levy & Trevarthen refer to data from Levy et al (1972) who apparently found (although this aspect of the results is not discussed in the original paper by Levy et al 1972) that in a test of pattern recognition where the right hemisphere was strongly dominant in a free-response condition, the left hemisphere in fact performed at a significantly superior level when it was brought into play (that is, when a verbal response was required), by comparison with the level of performance of the right hemisphere under free-response conditions. This could be compared with the present case, where those subjects who were right ear (left hemisphere) dominant for this task performed significantly better than those who were left ear (right hemisphere) dominant. One could imagine other tasks in which subjects using the right hemisphere outperformed subjects using the left.

The next chapter will begin by reviewing existing evidence for sex differences in cognitive processing and cerebral asymmetry and then two experiments will be described in which the interaction between the sex of the subject and the specific task requirements was examined.

Chapter 3

1. Sex differences in cerebral asymmetry

Buffery and Gray (1972) reviewed some of the evidence suggesting that males and females differ in spatial and linguistic ability. In discussing male superiority for spatial skill they begin with reports that the male rat is superior to the female in learning complex mazes and move on to summarise a variety of evidence for superior spatial abilities in male human beings as compared with females (when manipulation of spatial relationships is involved, but not on tasks relying on discrimination of fine visual detail), in both children and adults. Similarly they present evidence for female superiority for at least some verbal skills, in particular those which involve verbal fluency, again in both children and adults.

Next they discuss a variety of reports of differences in the pattern of cerebral asymmetry in males and females. Lansdell (1961, 1962, 1968) found differences between males and females on a variety of tests following unilateral lobectomy for epilepsy. Kimura (1969) found that males showed hemispheric differences on a dot localisation task while females did not. Kimura (1963) reported a significant REA in girls but not in boys at the age of 5 (these children were from a low-to-middle class socio-economic area; for children of above average IQ and from 'professional' families, Kimura found REA in both girls and boys from the age of 4). On the other hand, Knox & Kimura (1970) found that for non-verbal stimuli, such as environmental and animal noises, boys showed a greater left ear advantage than girls, and this led them to propose that males show greater right hemisphere lateralisation than females for spatial and non-verbal tasks.

Buffery and Gray concluded that:

> 'The innate neural mechanism for speech perception is more developed in the female than male brain of the same age, and this has two major consequences, the first direct and the second indirect:
>
> (a) The lateralisation of a usually left-sided cerebral dominance for language function is accelerated in the female brain and such functional topography facilitates the development of linguistic skill in women.
>
> (b) A more bilateral (though usually predominantly right-sided) cerebral representation for non-verbal function is established in the male than the female brain, and such functional topography facilitates the development of spatial skill in men.'

Buffery and Gray also produced some anatomical support for their argument for a difference in cerebral asymmetry between the sexes and referred to the finding by Matsubara (1960)

> 'that the right-sided vein of Trolard was larger than the left-sided vein in girls but not in boys. Since this vein is usually the major vein in the cerebral hemisphere opposite to that subserving speech (Di Chiro, 1962), this finding has been related to sex differences in cerebral dominance and in verbal skills (Lansdell 1964). Lansdell (1964) has also re-analysed the data of Conel (1963) on eight 4-year old brains. In four of the five female brains he found myelination greater in the left FAy hand area than in the right, whereas in all three male brains this was reversed. Lansdell's re-analysis also

> revealed that the number of exogenous fibres in layer 1 of areas Fay and PB was greater in the right in four of the female brains (one remaining unanalysed), but greater in the left for two of the three male brains.'

Further knowledge of the differences between the sexes in brain anatomy has been gained since Buffery and Gray's review. For instance, Wada et al (1975), in morphological observations on 100 adult and 100 infant brains, found significantly more female brains than male brains with reversed temporal planum asymmetry in the adult sample but not in the infant sample. Witelson & Pallie (1973) found that for female neonates, average age 8.8 days, the left planum was significantly larger than the right whereas in a sample of males of comparable age there was no such difference. However, for a sample of male neonate brains average age 33.8 days, the left planum was significantly larger than the right. More experimental data has also been collected, supporting the idea of sex differences in cerebral asymmetry but not necessarily supporting Buffery and Gray's conclusions as to the nature of the difference. Some of the more recent reports of differences in the pattern of asymmetry between the sexes for non-verbal stimuli will be reviewed in the next section and this will be followed by a review of some of the literature for verbal stimuli.

2. Sex differences in cerebral asymmetry for non-verbal material

An interesting and possibly relevant piece of work on Rhesus monkeys has been reported by Goldman et al (1974) who found that bilateral lesions of orbital prefrontal cortex carried out at 1-8 weeks in these monkeys resulted in impaired performance on tests involving spatial discrimination in male monkeys when tested at 2½ months of age, but in females comparable lesions did not induce deficits until the monkeys reached the age of 15 to 18 months.

Rizzolatti & Buchtel (1977) found a significant RVF superiority for males for face recognition but no consistent field advantage for females (and impaired performance relative to the RVF in males). This contrasts with other experiments in which females did show a RVF superiority for faces (for instance, Hilliard 1973; Patterson & Bradshaw 1975; Young & Ellis 1976) and led Rizzolatti and Buchtel to suggest that in fact specialised cognitive mechanisms may be lateralised to the same extent in males and females but their activation may depend on stimulus or environmental variables which äffect the two sexes differently. This makes the problem no less interesting but shifts the origin of sex differences from differences in lateralisation to a difference between the sexes in deployment of the two hemispheres for any given task, depending on the precise task requirements. In further support of the idea that it is not lateralisation per se which underlies the sex differences they cite the clinical findings that (a) no clear sex difference is apparent in the cognitive disturbances due to temporary blocking of the function of one hemisphere for diagnostic or therapeutic reasons (Pratt & Warrington 1972; Milner 1976) and (b) neuropsychological tests for localising brain damage on the basis of specific cognitive deficits are apparently as accurate in women as they are in men (personal experience of one of the authors, H.A.B.; Vinken & Bruyn 1969).

McGlone & Davidson (1973) reported that females, in contrast to males, who consistently showed higher left field scores, showed a higher incidence of RVF superiority on dot enumeration and they suggested that visual, nonverbal functions may be more dependent on the right hemisphere in males than in females. Although this is consistent with the results obtained by Kimura (1969) the fact that the data presented in the report confound the effects of handedness and sex makes interpretation difficult.

McGlone & Kertesz (1973) found a significant association between Block Design (Wechsler-Bellevue Intelligence Scale, Wechsler 1944) and language scores (from an aphasia battery developed by Goodglass & Kaplan 1972) for females with left hemisphere lesions, but not for females with right hemisphere lesions and not for males with lesions in either hemisphere, suggesting that females make more use of verbal mediation in 'non-verbal' tasks than do males. These authors also found that males with right hemisphere lesions tended to be worse on Block Design than all other groups, although this effect did not reach significance, and they argued from these results and from comparable data from other experiments, that specialisation of the right hemisphere for non-verbal, spatial functions is greater in males than in females.

Levy & Reid (1978) tested a large number of subjects falling into three major groups based on dominant writing hand and hand position in writing: non-inverted right-handed group; non-inverted left-handed group; inverted left-handed group, plus one subject showing an inverted right-handed pattern. They found that for all groups, including the right non-inverted group, the sex x field interaction was significant for a dot location test but was not significant for a syllable test (CVCs presented tachistoscopically). In the dot location test the performance of the male subjects was significantly better than performance of female subjects for LVF presentation but not for RVF presentation, i.e. field differences for females in the dot location test were smaller than those for males. This could suggest greater bilateralisation in females than in males for this skill. In this report, as in several others (Kail & Siegel 1978; McKeever & Van Deventer 1977; Lake & Bryden 1976) sex and field (or ear) differences interact in various ways with handedness and familial sinistrality. In the present review the results discussed are all for right-handed subjects, according to some criterion stated in the original reports; familial sinistrality has frequently not been assessed.

Finally, in this section, Witelson (1976a) presented evidence that the right hemisphere in males is already dominant for spatial processing by the age of 6 whereas in females spatial representation appears to be bilateral at least until the age of 13, which was the upper limit of the age range that she tested. She suggests that this lack of commitment of the right hemisphere to spatial processing in females may mean that that hemisphere is available to undertake verbal processing following left hemisphere injury, and this might account for the lower incidence of developmental language deficits in females compared with males (Critchley 1970; Benton 1964; Ingram 1959; Rutter et al 1971; Witelson 1976b). It might be noted at this point as a further indication of the different organisation of speech processes in males and females that females also have a better prognosis for recovery from aphasic precipitated by stroke (Luria 1970).

3. Sex differences in cerebral asymmetry for verbal material

Kail & Siegel (1978) found that for males recall of digits presented to the right visual field was significantly better than recall of digits presented to the left visual field. There was no significant difference between fields for women. Kail and Siegel concluded from this that there is greater hemispheric specificity for verbal functioning in men than in women. This is, of course, contrary to the model proposed by Buffery and Gray.

McGlone (1977), studying patients with unilateral brain lesions, reported that 48% (14/29) of the males, compared with 13% (2/16) of the females with left hemisphere damage fell into the aphasic category (assessed on the basis of 6 sub-tests from the Minnesota Test for the Differential Diagnosis of Aphasia, Schuell, 1965). Secondly, she found that when Verbal IQ was tested (Wechsler Adult Intelligence Scale, Wechsler 1955) left hemisphere lesions were associated with significantly lower scores than were right hemisphere lesions in males whereas in females both left and right hemisphere lesions were associated with comparable decrements in Verbal IQ scores. The decrement shown by the females was not as great as that shown by the left damaged males. Thirdly, when Verbal Memory was tested (Paired Associate and Logical Stories sub-tests from the Wechsler Memory Scale - Form 1, Wechsler and Stone, 1945) it was found that males with left hemisphere lesions obtained significantly lower verbal memory scores than males with right hemisphere lesions whereas for females a left hemisphere lesion did not reduce verbal recall scores significantly, compared with scores for female patients with right hemisphere lesions. Scores for the aphasic patients were not included in the analysis of Verbal IQ and Verbal Memory data, so it was not this which was responsible for the low verbal scores in men with left hemisphere lesions. Similarly, McGlone examined the aetiology, severity and locus of lesions and maintains that a similar pattern of sex differences existed across all groups. All these results led McGlone to propose that females possess a greater degree of bilateral speech representation than males (the reverse of the conclusion reached by Buffery and Gray).

McGlone (1978) appears to report on the same population of patients as McGlone (1977), although this is not stated and the figures for numbers of patients and for reports of data are all different. The conclusion is similar to McGlone (1977) - Verbal IQ deficits appeared only in men with left hemisphere lesions.

Marshall & Holmes (1974) presented verbs and nouns (CVCs) tachistoscopically to male and female subjects for recognition and found that while performance of males and females did not differ significantly with LVF presentation, males performed significantly better than females with RVF presentation.

On the other hand, McKeever & VanDeventer (1977) found a significant RVF superiority for right handed females for single letter stimuli presented tachistoscopically but failed to find a RVF superiority for males:

> 'In view of the fact that right-handed males have regularly shown significant RVF superiorities on word recognition in our laboratory, present results cannot be generalized to the form 'Right-handed males are not left hemisphere dominant for visual verbal processing.' The failure of RVF superiority among the right-handed males is clearly task-specific and consistent with the notion that lateral specialization is a graded - not all-or-none - characteristic. The admonition that different tasks may differentially tap hemispheric asymmetries is given weight by this finding, and it underscores the need for further study of the relationship between various laterality measures.'

It clearly also shows that different tasks differentially tap hemispheric asymmetries in the two sexes.

Day (1977) found that of his 46 subjects, 24 male and 22 female, 6 showed a left visual field advantage for abstract nouns. Of these six, five were female. This finding is very much in line with the data from Experiments 1 and 2 reported here.

Finally, two contrasting experiments. In the first, Johnson & Kozma (1977), subjects were required to balance a dowel rod on the right or left index finger while speaking, while remaining silent or while humming a melody. In males balancing times for the right hand decreased with concurrent verbalisation, but verbalisation had no effect on left hand performance in males or on the performance of either hand in females. In fact, the trend was towards a slightly worse performance for the left hand in females in the verbalisation condition compared with the control. The unimpaired performance of the right hand in females suggested that language functions were less clearly lateralised to the left in females than in males.

In contrast to this finding is the report by Low & Rebert (1978) that when subjects had to press a response key to verbs (but not to nouns, adverbs, etc) presented on a TV monitor, females showed slower reaction times with the right hand than with the left whereas in males, although left hand performance was comparable to that of females, their right hand performance was faster than their left hand performance. In this case it appears that the verbal processing in the left hemisphere was interacting with the right hemisphere motor response to a greater extent in females than in males - the opposite effect to that recorded by Johnson & Kozma.

Possibly the only safe conclusion to be drawn from all these studies is that there are indeed differences between the sexes in cerebral asymmetry for verbal and spatial skills, or at least there are sometimes differences between the sexes in the hemisphere which will be involved in a given task: the exact processing requirements of the task are a crucial factor. But perhaps even this is a less certain conclusion than it appears when one considers that many negative findings (no sex differences) will go unreported while any positive finding will be published. Add to this the fact that the results of possibly one in twenty experiments (assuming a 5% confidence level) will reflect just that sampling error that we strive so hard to control for by the use of statistics, and the ground becomes even more treacherous. Indeed this is a general hazard in the field of research into cerebral asymmetry. There was a great proliferation of research in the early and mid-1970s, which must have had the result that the sheer number of reports in which data were based on sampling error must have been considerable.

Nonetheless, the next experiment to be discussed examines the pattern of ear advantage in males and females in several tasks with different processing and output demands.

4. Experiment 3: To examine the direction of ear advantage in males and females in response to differing task requirements

Introduction

This investigation arose directly out of two of the findings of the first two experiments. The first was the trend, in both Experiment 1 and Experiment 2, towards LEA in females as compared with males. The second was that this trend was evident in the two dichotic recognition tasks reported here but was not evident in an earlier dichotic recall task (Perera 1971).

The present experiment therefore had several objectives:

1. To establish more reliably whether differences exist in direction of ear advantage between males and females in a dichotic recognition task with manual response.

2. To determine whether direction of ear advantage for a dichotic recognition task is reliably different from direction of ear advantage in a dichotic recall task, or whether the differences between the two experiments described here and the earlier dichotic recall experiment merely reflect sampling error.

3. To examine the effect on direction and magnitude of ear advantage of varying the task requirements. The recognition and recall experiments described differ from each other in various ways. For instance, the recognition tasks require a manual response whereas the recall experiment requires a verbal response. It could be argued that it is the need for a verbal response which underlies the involvement of the left hemisphere in the recall task and results in REA. On the other hand the recognition task requires that certain words be remembered for some time whereas the recall task involves quite different processing requirements and it could be that this is the important difference

between the tasks. The experiment to be described here attempts to separate out these variables in order to determine the effect of each on direction and magnitude of REA.

4. To compare the direction of ear advantage in males and females for a variety of different tasks.

The investigation involved the examination of ear asymmetries for four tasks: three dichotic recognition tasks and one dichotic recall task.

Recognition task (1): This was a reaction time task which required the subject to press a response button held in the left hand as soon as he heard the target word. This task was therefore similar to the two already reported, except that a different stimulus tape was used.

Recognition task (2): This was a reaction time task which required the subject to say 'yes' as soon as he heard the target word. This condition differs from task (1) in that it demands a verbal response. Comparison of the results from task (1) and from task (2) would thus reveal the extent to which REA arises as a consequence of left hemisphere activity in processing input and the extent to which it is the need for verbal output which gives the advantage to the left hemisphere. If in fact both hemispheres can process verbal input but only the left hemisphere can initiate output then it would be predicted that subjects might show LEA in task (1) who showed REA in task (2).

Recognition task (3): This was a reaction time task which required the subject to repeat the target word as soon as he heard it. This condition is thus similar to task (2) in that a verbal response is required, but the interest lies in any difference in ear advantage which might result from the different form of output required - the repetition of the word rather than the response 'yes'. There is some suggestion in the literature that the use of the words 'yes' and 'no' may sometimes involve a different mechanism, with a different hemispheric location, from that which underlies some other types of speech (Taylor 1932; Luria et al 1970). Thus Hughlings Jackson writes:

> "Most so-called speechless patients can utter the words 'yes' and 'no'.... The word 'no' may be uttered automatically by a speechless patient who cannot utter it voluntarily; he can reply 'no' when he cannot say 'no'".

> "There are three degrees of use of the word 'no'. It is used most voluntarily (as speech) when the patient can 'say' it when told. It is used more automatically when the patient can 'utter' it in reply correctly; and it is used most automatically when it comes out like an ordinary interjection with states of feeling." (Taylor 1932, p.134).

Recall task: This was a dichotic recall task. Insofar as it involves repetition of input, it is comparable to recognition task (3). If there is any difference in pattern of ear advantage between the recall task and recognition task (3) then the difference must arise from the different processing requirements of the two tasks.

Method

Preparation of stimulus material

Recognition tasks

The tape for the recognition tasks was again prepared using DITMA and it comprised 240 dichotic pairs. 80 of the pairs included the target stimulus 'bel'. The matrix words were: 'roc', 'jam', 'cum', 'tin' and 'wil', which were randomly paired with each other and with 'bel' such that a given word was never paired with itself and each word was associated with each other word an equal number of times. The target stimulus occurred 40 times on each channel. Four seconds elapsed between onset of one pair and onset of the next pair.

Recall task

The tape for the recall task was also prepared using DITMA and comprised 40 dichotic pairs of words presented at the rate of 2 pairs/second, with a five second pause after every two pairs.

Subjects

Subjects were 12 males and 12 females, undergraduates of the University of Warwick. All were self-classified right-handers, with no known left-handed relatives and no known hearing defect. Each subject participated in all four tasks.

Procedure

Recognition tasks

The stimulus tape was played on a Tandberg Cross-field Series 3500X tape recorder. The onset of the target word triggered a timer (Racal Universal Counter 9835) which was stopped by the manual or verbal response. Reaction times were recorded by hand. Reaction times greater than 1499 msec were excluded.

Subjects were instructed verbally either to press the hand held response key with the left index finger (task 1), or to say 'yes' (task 2), or to repeat the target word (task 3), as soon as possible after hearing the target stimulus.

The manual task was always performed first. It was felt that after a long period of verbal responding, a bias towards the left hemisphere might be created and any redistribution of hemispheric activity to meet the different demands of the manual task might be prevented.

The order of presentation of the other two recognition tasks was counterbalanced.

Subjects heard the stimuli through Sennheiser HD 414 stereo headphones. The 240 dichotic pairs were divided into four blocks of 60 pairs, each block containing 20 target words occurring randomly and equally often at either ear. Two-minute rest pauses were given between blocks and headphone orientation was reversed after each block.

Twelve practice trials were given before each of the three tasks. Five minutes rest was given between tasks.

Recall task

Subjects were instructed to recall as many of the four words (two pairs) as they could, in any order, in the 5 second interval following their presentation. There were 20 such trials, divided into two groups of 10 with a two minute rest pause between them. Headphone orientation was reversed for the second block. Five practice trials were given.

The recall task was always performed after the recognition tasks, again to avoid setting up a bias towards the left hemisphere.

Results

Data are summarised on Table 8 and are shown on the histogram in Figure 13. Means for individual subjects are given in Table 9 and standard deviations in Appendix 3.1.

(1) An analysis of variance was carried out on the data for the three recognition tasks. There was a significant difference in mean RT between the three tasks ($F(2,44) = 36.27$, $p<.001$) and a significant difference between ears ($F(1,22) = 15.50$, $p<.001$). A Tukey test was carried out to investigate the difference in mean RT in the three tasks. The means were as follows: task 1, 294.0 msec; task 2, 431.5 msec; task 3, 441.3 msec. For any two means to be significantly different from each other at the .05 level the

Table 8

(1) Mean reaction times (msec) for each of the three recognition tasks;

(2) Mean number of words correctly recalled from each ear in the recall task. Total number of words presented to each ear = 40. (N=12 for each entry)

	Task 1 (manual)		Task 2 ('yes')		Task 3 ('bel')		Recall Task	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
Male subjects	291.8	267.9	422.7	391.3	445.2	408.6	19	25
Female subjects	341.5	274.9	482.8	429.3	487.4	423.9	21	26

Figure 13

Histogram showing (i) mean RTs for each ear for males and females for each of the three dichotic recognition tasks, and (ii) mean number of words recalled in the dichotic recall task. (N = 12)

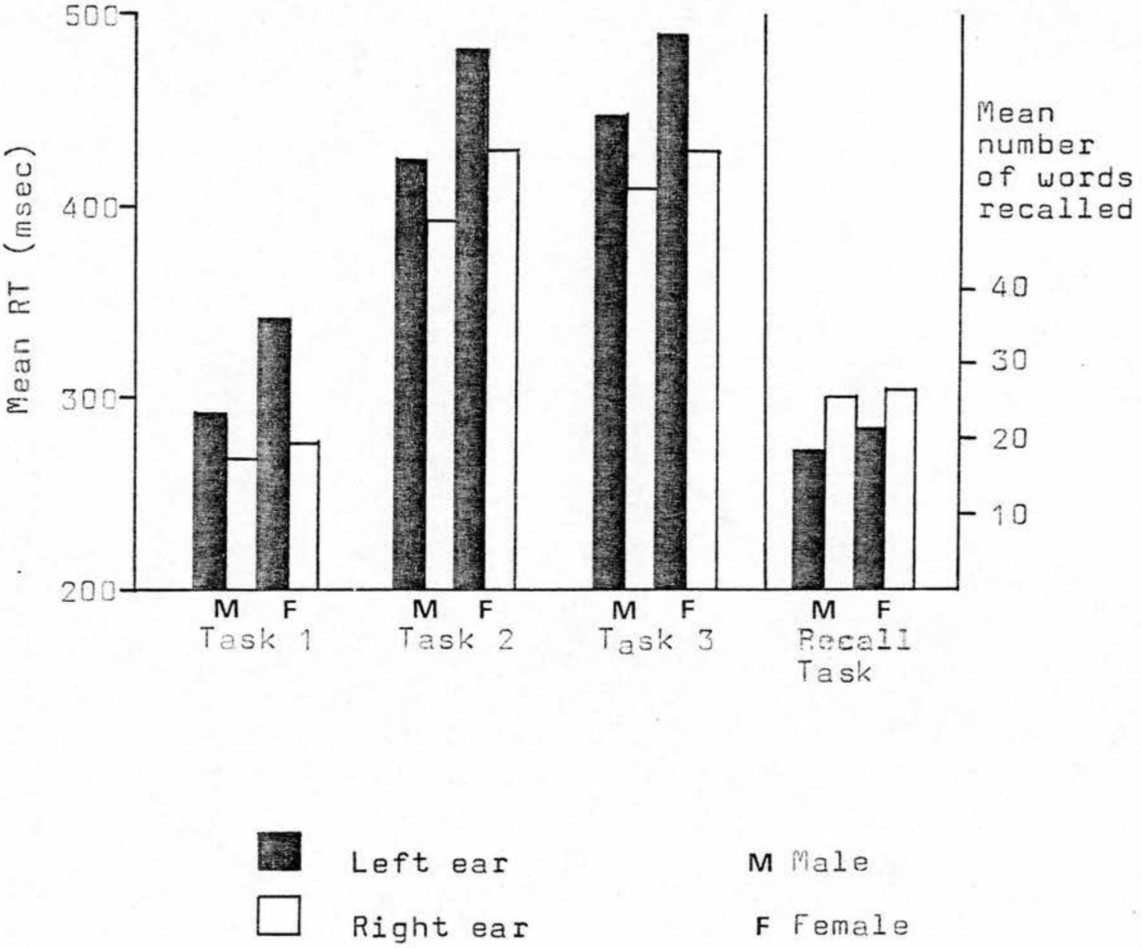


Table 9

Data for individual subjects showing: (1) mean reaction time (msec) for each ear for each of the three recognition tasks; (2) total number of words recalled from each ear in the recall task (maximum possible = 40).

Male Subjects *Indicates LEA

	Task 1 (manual)		Task 2 ('yes')		Task 3 ('bel')		Recall Task	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
1.	193.7	271.6*	238.8	226.8	237.4	275.8*	24	20*
2.	428.8	394.1	413.6	371.0	648.6	486.0	29	27*
3.	264.0	290.2*	416.3	392.3	478.9	491.7*	21	26
4.	266.5	250.2	486.1	442.3	527.0	477.3	17	32
5.	406.1	239.0	607.0	455.4	567.4	427.2	10	29
6.	140.3	195.2*	351.7	379.1*	257.5	325.0*	16	27
7.	321.3	244.0	464.7	458.7	458.5	416.1	21	21
8.	288.3	281.1	434.0	401.1	349.8	310.6	19	24
9.	272.5	201.0	426.5	432.5*	480.6	479.9	19	17*
10.	484.8	495.1*	661.5	643.4	690.6	671.0	16	26
11.	143.0	158.7*	156.1	154.7	130.6	149.7*	10	20
12.	292.7	194.6	416.3	337.8	516.0	392.4	20	29

Table 9 (contd)

Data for individual subjects showing: (1) mean reaction time (msec) for each ear for each of the three recognition tasks; (2) total number of words recalled from each ear in the recall task (maximum possible = 40).

Female Subjects *Indicates LEA

	Task 1 (manual)		Task 2 ('yes')		Task 3 ('bel')		Recall Task	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
1.	403.8	459.4*	566.7	565.5	656.8	557.5	17	18
2.	442.8	338.0	614.7	540.1	559.8	501.9	24	28
3.	398.9	265.6	764.0	734.0	872.6	840.1	19	25
4.	185.7	232.0*	262.4	213.1	205.9	210.6*	23	29
5.	407.0	180.5	512.2	440.8	455.6	292.7	20	25
6.	394.0	290.6	596.9	471.6	619.3	519.1	23	30
7.	492.5	265.6	378.1	368.7	425.8	411.9	22	24
8.	345.0	345.4*	482.7	389.1	544.4	457.1	14	24
9.	243.2	290.3*	458.8	469.1*	310.6	359.7*	25	23*
10.	311.1	264.1	408.8	403.7	372.2	367.6	29	32
11.	211.7	164.3	323.1	269.7	345.2	308.7	18	26
12.	261.9	202.5	424.8	286.2	480.5	259.8	19	26

difference between them must equal or exceed 47.04 msec. Clearly the mean RT for task 1 differs significantly from the mean RT for either of the other tasks while the mean RTs for tasks 2 and 3 do not differ significantly from each other.

No other main effects or interactions reached significance. The summary table for this analysis is given in Appendix 3.2.

The absence of a sex x ear interaction or a sex x ear x task interaction confirms what can be seen by inspection of the data for individual subjects given in Table 9, namely that there is no difference in direction of ear advantage between sexes for either manual or verbal recognition tasks. The trends shown in Experiments 1 and 2 were thus not confirmed.

(2) An analysis of variance was carried out on the data from the dichotic recall task. This revealed a significant difference between ears ($F(1,22) = 23.0$, $p<.001$) but no significant difference between sexes and no sex x ear interaction. Details of this analysis are given in Appendix 3.3.

(3) Comparison between the number of individuals showing LEA on the manual recognition task and on the recall task shows that 9 subjects demonstrate LEA on the recognition task and 4 on the recall task. There seems to be a gradient across the tasks, with 9 subjects showing LEA on the manual recognition task, 6 showing LEA on recognition task 3 ('bel'), 4 showing

LEA on the recall task and 3 showing LEA on recognition task 2 ('yes'). All six subjects showing LEA in task 3 also show LEA in task 1. Only one subject shows a left ear advantage in all four tasks.

Discussion

1. The first objective of this experiment was to establish more reliably whether differences exist in direction of ear advantage for males and females in a dichotic recognition task with manual response. The results from Task 1, the manual recognition task, lend no support to the idea of such a difference and thus fail to confirm the trend towards LEA in females shown in a similar task in Experiments 1 and 2.

2. The second objective was to determine whether direction of ear advantage for a dichotic recognition task requiring manual response was reliably different from direction of ear advantage in a dichotic recall task. The present experiment confirms the earlier finding of a greater proportion of subjects showing LEA in the recognition task than in the recall task. In this case 7 of the 9 subjects showing LEA in the manual recognition task showed REA in the dichotic recall task.

3. The third objective was to investigate the differences in direction and magnitude of ear advantage in the recognition tasks and in the recall task in order to find out whether such differences were the result of the requirement for a verbal response in the recall task as compared with the manual

recognition task or whether there was some other factor in the recall task which necessitated left hemisphere involvement.

The analysis of variance, which revealed no significant difference in asymmetry between the three recognition tasks, two of which involved verbal response, suggests strongly that the difference between the manual recognition task and the recall task does not arise because of the need for verbal response in the latter case. This conclusion is reinforced by observation of the data for individual subjects where it will be seen that 6 of the 9 subjects showing LEA on the manual recognition task also showed LEA for the verbal response 'bel'. It is curious that a similar pattern is not observed for the verbal response 'yes'. One could envisage some form of gradient of right hemisphere involvement with at one end the manual recognition task requiring no verbal output and therefore allowing right hemisphere mediation, followed by the response 'bel', which is almost equally within the capacity of the right hemisphere. The response 'yes' and the recall task both appear to require a greater degree of left hemisphere involvement. That it is the response 'bel' rather than the response 'yes' which is associated with a left ear advantage and which is apparently initiated by the right hemisphere is the reverse of the outcome which might have been expected based on the argument put forward by Hughlings Jackson.

4. The fourth objective was to compare the direction of ear advantage in males and females for a variety of different tasks. As with Task 1 so with the other three tasks: there was no trend towards a difference between the sexes in direction of ear advantage.

The absence of any difference between sexes in direction of ear advantage in the manual reaction time task where it had been suggested in the earlier experiments is odd and leads to a closer examination of the differences between this experiment and the earlier two. The only difference lies in the number of target stimuli which the subjects had to identify: in Experiments 1 and 2, six targets; in Experiment 3, only one target. Retrospectively this appears to be an important change in procedure, possibly altering the nature of the task.

The next experiment follows this up and seeks to determine whether it is the difference in task requirements in Experiments 1 and 2 compared with Experiment 3 which led to the absence of any trend towards sex differences and also, by giving yet another chance for sex differences to appear, to show whether the results of Experiments 1 and 2 were simply sampling error and the data of Experiment 3 more representative.

5. Experiment 4: To examine the magnitude and direction of ear advantage in males and females in two tasks with different processing demands

Introduction

Experiment 4 was designed to examine any differences between males and females in direction of ear advantage in two tasks with different processing demands, the first representing the situation in Experiments 1 and 2, i.e. a manual response to any one of six target stimuli, and the second the situation represented by Experiment 3, a manual response to only one target stimulus. The prediction, in the light of the first three experiments, was that more females than males would show LEA in the multiple target condition and that this difference would be more marked in that condition than in the single target condition.

Method

Preparation of material

Two tapes were prepared. The first made use of twelve blocks of stimulus material from experiment 2, with the same inter-stimulus and inter-block intervals. The second tape was quite simply the same as that used in experiment 3.

Subjects

Subjects were 16 males and 16 females, students and staff of the University of Warwick and of the Open University.

Procedure

Subjects were given the following written instructions for the single target condition:

When you put on the headphones you will hear a series of words. These words will be presented in pairs, one word to each ear. Each time you hear the following word:

BELL

press the button as quickly as possible. The time that you take to respond to this word will be recorded. Please hold the response button in your left hand and press it with your left index finger.

Remember, press the button as quickly as you can after hearing the target word.

Instructions for the multiple target condition were similar, except that the six target stimuli were listed in place of BELL and appropriate changes were made in the wording of the rest of the instructions.

Headphone orientation was balanced between subjects and within sex-grouping, as was order of presentation of the two tasks. As with the earlier experiments two practice blocks were given in the multiple target task before the instructions were removed and twelve practice pairs in the single target task. Reaction times exceeding 1499 msec were excluded.

Although subjects were asked to attend to all six targets in the multiple target condition, RTs to the word 'full' were discounted since responses to this stimulus tended to be erratic - responses were either relatively slow or were missed altogether.

Results

Mean RTs for each task are shown on Table 10. Mean RTs and corresponding standard deviations for individual subjects are given in Appendix 4.1 and 4.2.

An analysis of variance revealed a significant difference between ears ($F(1,30) = 9.36$, $.01 > p > .001$) and a significant difference between tasks ($F(1,30) = 552.8$, $p < .001$) responses in the single target condition being faster than responses in the multiple target condition. The male/female difference failed to reach significance ($F(1,30) = .09$, n.s.). Although Table 10 suggests that the degree of ear advantage is greater for the single target condition (L-R = 59.8 msec for males and 70.5 msec for females) than for the multiple target condition (L-R = 33.9 msec for males and 18.8 msec for females) this difference did not reach significance. The summary table for this analysis is given in Appendix 4.3.

Discussion

The predictions being tested in this experiment were: (1) that more females than males would show LEA in the multiple target condition and (2) that this effect would be more marked in the multiple target condition than in the single target condition.

This experiment did not reveal any significant difference between males and females in direction or magnitude of ear advantage in either task, although there was still a slight tendency towards LEA in

Table 10

Mean reaction time (msec) for each ear for each task.
(N=16 for each entry)

	Male Subjects		Female Subjects	
	Left Ear	Right Ear	Left Ear	Right Ear
Multiple target	798.7	764.8	775.3	756.5
Single target	443.0	383.2	445.0	374.5

females compared with the males, i.e. two more females than males showed LEA in each of the two tasks. To suggest with any seriousness that this is indicative of a difference in asymmetry between males and females would clearly be clutching at straws.

The multiple target condition resulted in slower reaction times than the single target condition but had no effect on either direction or magnitude of ear advantage.

6. A review of the first four experiments

The first two experiments, discussed in Chapter 2, attempted to provide conditions in which the right hemisphere could manifest any speech processing facility it possessed, the two conditions being practice and the availability of a manual response, a means of expression not always given in dichotic listening experiments. The particular predictions made concerning improvement in speed of response to right and left ear inputs with practice were not confirmed, and the only sign of right hemisphere speech processing was shown in the relatively large number of females who showed a left ear advantage on this task, compared with males. Although this effect did not reach significance in either experiment the trend towards more females than males showing a left ear advantage appeared in both experiments.

The third experiment compared the pattern of ear advantage in males and females (i) for a dichotic recognition task with manual response, similar to

Experiments 1 and 2 except that there was only one target stimulus to which a response had to be made; (ii) for two recognition tasks which required verbal response, either 'yes' or 'bel'; (iii) for a dichotic recall task. This experiment failed to confirm the trend towards LEA in females in a dichotic recognition task with manual response. It confirmed that subjects who showed LEA on a dichotic recognition task with manual response were likely to show REA on a dichotic recall task, although the tendency for these subjects to show LEA on a dichotic recognition task with the verbal response 'bel' suggests that it was not the requirement for a verbal response *per se* in the dichotic recall task which resulted in a right ear advantage - if this were the case these subjects should have shown a right ear advantage in the recognition task with verbal response. Rather it seems possible that in subjects showing LEA on the recognition task with verbal response the right hemisphere processed input and programmed the verbal output, but in the recall task, which involved the processing of four verbal stimuli, storage and verbal recall, only the left hemisphere could meet the task demands and hence there was a right ear advantage.

Experiment 4 compared the magnitude of ear advantage in males and females in two manual recognition tasks, one involving a single target word to which response had to be made, the other requiring a response to any one of six target stimuli. There was no difference between the sexes in magnitude or direction of ear advantage for either of the tasks and no trend towards such a difference - the findings of Experiments 1 and 2 were thus not replicated. There was no difference between the two tasks in magnitude of ear advantage elicited.

In all the experiments a (not significant) number of subjects have shown a left ear advantage with manual response, which presumably indicated that in these individuals the right hemisphere was processing input and initiating manual output. The results of Experiment 3 are interesting in that they suggest that in these subjects the right hemisphere also appears to be able to initiate the verbal response 'bel' but not to be able to perform the processing involved in a dichotic recall task. There is no way of knowing at this point which stage of the processing it is that the right hemisphere cannot perform. The subjects showing LEA on the manual recognition task and apparently initiating a verbal response from the right hemisphere are of course subjects who would normally be classified as left hemisphere dominant for speech on the basis of the direction of ear advantage shown on the dichotic recall task.

In the next chapter two further experiments will be described which attempt in other ways to provide the conditions in which right hemisphere speech processing might be demonstrated.

Chapter 4

1. Experiment 5: To examine the effect of a secondary verbal task on dichotic listening performance

Introduction

This experiment was a further attempt to provide conditions under which the right hemisphere might demonstrate any ability it possesses for processing verbal input. The method employed this time involved, in addition to a dichotic listening task, the use of a secondary verbal task.

Geffen et al (1973) found faster verbal reaction times (the response required was 'Bonk') to left visual field stimuli than to right visual field stimuli when the left hemisphere was occupied with a dichotic detection task as a secondary verbal task. In the absence of the secondary task, response to digits presented to the right visual field was faster than response to left visual field stimuli. This is the first and only report (except for Experiment 3 in the present series of experiments) of evidence suggesting that the right hemisphere can initiate a verbal response in normal subjects as opposed to subjects who are in some way brain-damaged. It thus appears that, when a secondary verbal test has to be performed, the right hemisphere can undertake both the processing of the verbal input and the initiation of the response.

Something similar has been reported by Hellige and his co-workers, as described in Chapter 1. Hellige & Cox (1976) and Hellige (1978) found a reduction in size of right field advantage for verbal material when a concurrent verbal task had to be performed and Hellige et al (1979) found a reversal of the field advantage in the presence of a secondary task, such that reaction times became faster to left visual field verbal stimuli. Again this appears to reveal a right hemisphere ability to perform the primary task.

In the experiment to be described subjects were required to perform a dichotic recognition task, as in Experiments 1 - 4, direction of ear advantage being calculated from manual reaction time to the target stimuli. The primary task is thus the same as that described in Experiment 3: Task 1 and Experiment 4: single target condition. In addition to this task subjects were instructed to count (to themselves) in threes. This particular task was chosen as the secondary task (i.e. as the task which would engage the left hemisphere speech processor) (a) because it might be supposed to necessitate covert verbalisation; (b) because digit recall or recognition tasks have been shown to elicit a right ear advantage (Kimura 1961a, 1961b; Levy & Bowers 1974); (c) split-brain data suggest that the left hemisphere is involved in calculation (Gazzaniga & Sperry 1967).

The theory underlying this procedure is that the secondary task will occupy the left hemisphere and that the right hemisphere might then intervene in the dichotic recognition task. One could envisage two possible reasons for this, the first that since the left hemisphere is occupied with the concurrent, secondary, task the right hemisphere is in some sense freed to operate independently and the second that when two verbal tasks have to be performed simultaneously every available speech processing mechanism must be brought into operation in order to carry out the task, and thus if the left hemisphere is overloaded the right will be brought into play.

The present task should be easier for the right hemisphere than that devised by Geffen et al in that the required response to the primary task is manual rather than verbal. It is thus a test only of the ability of the right hemisphere to process speech input rather than a combined test of its ability both to process verbal input and to initiate verbal output as was the case in Geffen et al's experiment.

The prediction is that when a secondary verbal task has to be performed, manual response to right ear inputs will be more greatly affected than manual response to left ear inputs, since right ear inputs have to compete for processing time with the concurrent verbal task, possibly to such an extent that response to left ear inputs becomes faster than response to right ear inputs. If, however, the left hemisphere continues to process the dichotic inputs while the secondary task is being performed then both right and left ear inputs will be equally affected by the secondary processing and reaction times to both ears will increase equally.

There is also a third possibility and that is that the performance of the secondary verbal task by the left hemisphere might cause an attentional bias to the right. Such an outcome might be predicted from an attentional model of auditory asymmetry (Kinsbourne 1970) which proposes that left hemisphere activation generates orientation to the right and that it is this, rather than occlusion of the ipsilateral pathway, which leads to a right ear advantage in dichotic listening experiments. Kinsbourne found that when subjects had to retain a list of 6 one-syllable words in memory while carrying out a tachistoscopic gap detection task they displayed a right visual field advantage where otherwise there was no field advantage. For a useful discussion of Kinsbourne's model and of the adaptations proposed by Hellige et al (1979) see Cohen (1979). For reports which failed to confirm predictions generated by Kinsbourne's model see Allard & Bryden (1979); Kallman (1978).

In the present experiment, following Kinsbourne's model, one might predict that when a secondary task has to be performed responses to the left ear input in a dichotic listening task would be adversely affected i.e. reaction times to left ear inputs would increase relative to reaction times to right ear input and also relative to left ear RTs in the absence of a secondary task, since right ear input would be given increased attention. Such a prediction was clearly not borne out in the case of the experiments performed by Hellige et al or by Geffen et al. It was not confirmed by Allard & Bryden (1979) who, using visually presented verbal material in their concurrent task, found no significant increase in ear advantage for dichotic stop consonants when the concurrent task had to be performed. Neither was any support given by the work of Rizzolatti et al (1979) who found a stronger and more consistent _LVF_ advantage for a light stimulus when a concurrent verbal task had to be performed than in the absence of the concurrent task. On the other hand Hellige & Cox (1976) found a RVF advantage for a nonverbal task in the presence of a concurrent verbal task (where there had been a slight LVF advantage with no concurrent task) but a LVF advantage for the same stimuli when the concurrent task was made more difficult (size of memory set was increased). Clearly there is some point at which the advantage given to right-sided input due to the verbal set established in the left hemisphere becomes outweighed by the mutual interference produced between the processing demands of the concurrent task and those of the primary task. These authors also found no increase in RVF advantage for recognition of 4-letter words when a memory load of 2 or 4 nouns was added compared with a no memory load condition. They suggest that the primary word recognition task itself activates the left hemisphere such that the imposition of a memory load has no additional activating effect.

Method

Preparation of stimulus material

A stimulus tape was constructed comprising two of the four blocks of stimuli used in Experiment 3 for the recognition tasks and in Experiment 4 for the single target condition. The tape thus consisted of two blocks of 60 pairs of dichotic stimuli, each block containing 20 target stimuli occurring randomly and equally often at either ear. t-tests performed on pilot data for individual subjects showed that a significant REA could be obtained using this number of stimuli.

Subjects

Subjects were students and staff of Warwick University all of whom fulfilled the requirements detailed in the earlier experiments. Subjects were tested until four males and four females had been found who showed a right ear advantage on the control task (dichotic recognition task with no secondary task). In all eleven subjects were run, three (1 male and 2 females) showing a left ear advantage on the control task. Data for these subjects are shown but are not included in the main analysis.

Procedure

For the dichotic recognition task subjects were instructed orally to press the response button as soon as possible after hearing the target stimulus in either ear. Half of the subjects of each sex responded with the left index finger and the other half with the right index finger. A two minute rest pause was given between the two blocks.

There were two conditions: (i) a dichotic recognition task with manual response; (ii) a dichotic recognition task with manual response with a secondary verbal task. In the second condition subjects were instructed to count to themselves in threes, starting either at 3 or 4 (a starting number was given). Twelve practice trials were given before the two experimental blocks in both conditions and in condition (ii) subjects were asked how far they had counted both after the practice trials and after each of the experimental blocks and then started counting again from the beginning. Subjects started at 3 for the practice trials and for block 1 and from 4 for block 2.

The order of presentation of the two tasks and the orientation of the headphones were counterbalanced across subjects and across sexes.

Reaction times over 999 msec were discarded.

Results

Reaction times for the two ears in the two conditions are given in Table 11 and illustrated in Figure 14. Mean reaction times and standard deviations for individual subjects are given in Appendix 5.1 and 5.2.

Analysis of the data confirmed that subjects showed a significant right ear advantage ($F(1,4) = 29.30$, $.01 > p > .001$). This is hardly surprising since subjects were selected on the basis of this criterion. There was a very significant task effect ($F(1,4) = 118.14$, $p < .001$), with faster reaction times where no secondary task had to be performed. Interestingly there was also a significant sex x task interaction $F(1,4) = 18.18$, $.05 > p > .01$), reaction times for females being significantly more affected than reaction times for males by the performance of the secondary task. Despite this difficulty males and females apparently counted at roughly comparable rates - figures reached at the end of the first block of stimuli were 529, 344, 426 and 234 for the males and 457, 350, 363 and 429 for the females. Figures reached at the end of the second block were similar.

No other main effects or interactions reached significance. The summary table for the analysis of variance is given in Appendix 5.3.

Discussion

The prediction being tested in this experiment was that when a secondary verbal task had to be performed, manual response to right ear inputs in a dichotic

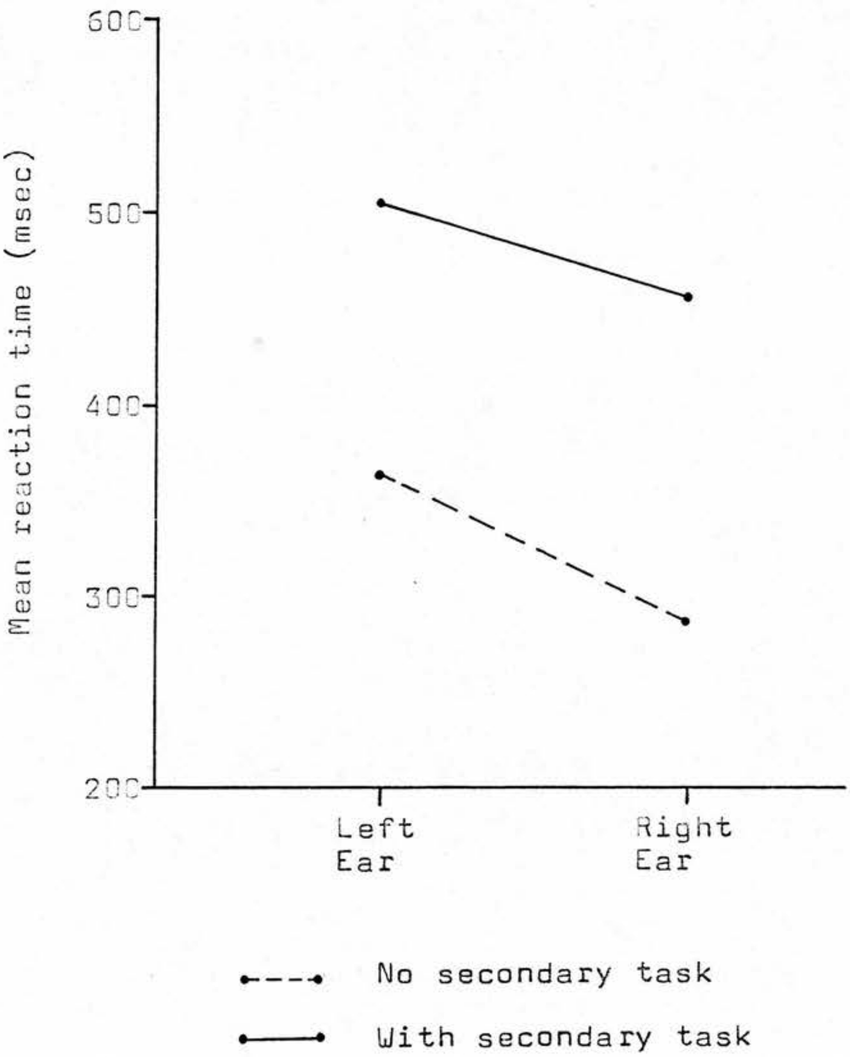
Table 11

Mean reaction time (msec) for each ear in the two experimental conditions: (i) dichotic recognition task with no secondary task; (ii) dichotic recognition task with secondary verbal task. (N=8)

	Left Ear	Right Ear
Condition (i)	361.1	286.5
Condition (ii)	503.1	454.2

Figure 14

Mean reaction time (msec) for each ear in the two experimental conditions:
(i) dichotic recognition task without secondary task
(ii) dichotic recognition task with secondary task.
(N = 8)



listening task would be more greatly affected than response to left ear inputs, possibly to such an extent that response to left ear inputs became faster than that to right ear inputs. This prediction was not verified: response to both right ear inputs and to left ear inputs appear to be equally affected by performance of the secondary task and the assumption must be that this indicates that the left hemisphere continued to process both items of each dichotic pair and at the same time carried out the secondary counting task. The only effect of the secondary task was to significantly increase the time taken to respond to the dichotic stimuli. There is no evidence of right hemisphere intervention of the kind reported by Geffen et al or by Hellige et al and thus no evidence that the right hemisphere is able to process verbal input.

The nature of this task was of course in many ways different from that of either Geffen et al or Hellige et al. Geffen et al used a visual digit recognition task as the primary task and Hellige et al also used a visually presented task - same/different judgements of upper and lower case letters presented simultaneously in the same visual field. The elusiveness of the effect is such that even Hellige et al only found this reversal of field advantage for same judgements and not for different judgements. The secondary task employed by Geffen et al was a dichotic detection task, in which the subject was required to press a button when he heard the letter 'V' at either ear. In the case of Hellige et al, the secondary task was to remember 2, 4 or 6 words. The response required to the primary task by Geffen et al was verbal - 'Bonk', while that of Hellige et al and in the present experiment was manual.

The most obvious way in which these two experiments both differ from that reported here is with regard to the nature of the stimuli in the primary task - in both cases input was visual whereas in the present experiment it was auditory. It thus appears that the visual processing of letter stimuli demanded by Geffen et al and Hellige et al was within the capacity of the right hemisphere whereas the processing of the auditory input 'bel' was not, although one might have supposed that such a stimulus might have been within the range of the right hemisphere simply as a particular recurrent auditory stimulus. It is possible that the need to discriminate 'bel' from 'wil', one of the matrix items which resembles it fairly closely, might have put this recognition task outside the capacity of the right hemisphere. This possibility is entirely speculative since there is no evidence from the data in the form of false positive responses (of which there were only a handful over all subjects in each experiment) or comments from subjects about their responses that lends any support to it.

An alternative explanation for this difference between Geffen et al and Hellige et al's work and the present study could be that the total processing demand of their tasks was greater than that of the task described here so that the left hemisphere was overloaded in their experiments but not in this one. There is no way of analysing the processing demands of the two situations but there is certainly no obvious reason to suppose that this was the case.

A second prediction discussed in the introduction, that performance of a secondary verbal task might bias attention to the right and thus facilitate response to right ear targets relative to left ear targets, was also not confirmed. This is consistent with the findings of other experiments discussed earlier.

That the performance of the female subjects on the dichotic listening task would be more affected by the concurrent secondary task than was the performance of the male subjects was not predicted and suggests that the verbal processing capacity of the left hemisphere in females is more limited than that of males. If this were the case it would be an interesting addition to the literature on cognitive processing in males and females which has suggested female superiority for at least some verbal tasks.

2. Introduction to Experiment 6

Experiment 6 attempted to provide conditions under which any right hemisphere speech processing capacity might be revealed by directing attention either to the right or to the left ear in dichotic recognition task similar to those already described.

Evidence for an attentional bias to the right for speech comes for instance from Oxbury et al (1967) who found no significant REA when order of report was controlled such that the tendency for right ear inputs to be recalled first was counteracted. Oxbury et al (1967) and Treisman & Geffen (1968) found a significantly higher proportion of intrusion errors when the unattended channel was on the right than when it was on the left. On the other hand Myers (1970), although finding a slightly reduced right ear advantage when the ear to which the subject was to respond was precued, found no significant difference between the size of ear advantage in this condition compared with three other conditions of stimulus cueing which allowed little or no opportunity for attention to be switched to the cued channel. It thus appears that although a bias of attention towards the right is undoubtedly one component of the right ear advantage it is not the only one.

The purpose of this experiment was to reduce any possible bias towards attending to input to the right ear rather than input to the left, by instructing subjects to attend only to one ear and by presenting target stimuli only on the attended channel and not on the unattended channel (thus preventing any distraction towards the unattended channel) and then, having reduced this bias, to provide a non-verbal response to further reduce the necessity for left hemisphere intervention. It was hoped that this set of conditions might enable the right hemisphere to display any speech processing capacity it might possess.

The prediction being tested in this experiment was thus that where attention was directed to the left ear, manual response times to left ear input would improve significantly compared with response times to left ear input in the unattended condition and that this improvement would be more marked than comparable improvement in response to right ear inputs.

There are two possible reasons why the predicted results might be obtained: (i) When attention is directed to the left ear input a natural bias towards attending to the right ear is counteracted and hence reaction times to left ear inputs will become faster in the attended condition. Speed of reaction time to attended right ear inputs would not be expected to improve to the same extent. (ii) When the attentional bias towards the right ear is reduced, right ear inputs no longer have priority and the two hemispheres can compete on more equal terms. In such a situation any speech processing capacity of the right hemisphere should be manifest and reveal itself in significantly faster reaction times for left ear inputs in the attended condition. Again, improvement in speed of reaction time to attended right ear inputs would not be predicted to be as great.

The first part of the experiment, Experiment 6(i), was designed to establish whether the predicted pattern of results was obtained; the second part, Experiment 6(ii), distinguishes between the two possible mechanisms underlying the results.

3. Experiment 6(i): To examine the effect on manual reaction time of directing attention to the right or left ear in a dichotic listening task

Method

Preparation of stimulus material

Two tapes were used. The first, Tape 1, was the same as that used in Experiment 5, and comprised 40 target stimuli equally distributed between ears. The second tape, Tape 2, was similar except that all the target stimuli had been transferred onto a single channel and thus the ear to which target stimuli were presented depended on the orientation of the headphones. This tape also comprised 40 target items, all of which would be presented to the same ear. Two such tapes were constructed, one of which was used when attention was directed to one ear and the other when attention was directed to the other ear. This avoided repetition. Tape 1 and the two versions of Tape 2 were all of the same duration.

Subjects

Subjects were students and staff of the University of Warwick who fulfilled the criteria for handedness and the other conditions described in Experiment 1. Subjects were tested until 8 males and 8 females showing REA on Tape 1 (the control condition in which attention was not specifically directed to either ear), had been found. This involved testing a total of 22 subjects, 6 of whom (2 males and 4 females) showed LEA. Data are given for the subjects showing a left ear advantage but they were not included in the analysis.

This experiment and Experiment 5 were run at the same time and some subjects participated in both experiments. With this limitation the proportions of males and females showing LEA in Experiments 5 and 6(i) can be taken as a general indication of the proportions in the whole population.

Procedure

Each subject performed in both conditions:

(i) attention not directed;

(ii) attention directed to (a) the right ear
(b) the left ear;

in random order. Thus half of the males and half of the females first performed in the non-directed condition and then in the directed condition and half in the opposite order.

Half of the subjects of each sex responded with the left hand in both conditions and the other half with the right hand. In the non-directed condition headphone orientation was counterbalanced within each sex x hand combination. In the attended condition half of the subjects of each sex attended to the left ear while Tape 2 was presented and then attended to the right ear while Tape 2 was presented again (in its alternative version) and the other 8 subjects attended first to the right ear and then to the left ear. All four randomised elements: order of performance of the two conditions (non-directed/directed), hand used for making the response, headphone orientation in the non-directed condition and ear to which attention was directed in the attended condition (either to the left and then to the right or vice versa) were completely counterbalanced within the 8 subjects of each sex.

Subjects were instructed orally to press the response key as quickly as possible on hearing the target stimulus. In the attended condition they were informed that no target stimuli would be presented to the unattended ear.

12 practice trials (which included 4 presentations of the target stimulus) were given before presentation of the experimental stimuli for the non-directed condition and before each of the presentations of Tape 2 in the attended condition.

As in Experiment 5, Tape 1 comprised two blocks of stimuli, and a two minute rest pause was given between the two blocks. Tape 2 was also divided into two blocks (each block thus containing 20 target stimuli presented to the same ear) and a two minute rest given between blocks. A two minute rest pause was also given before subjects performed in the second condition, whichever that happened to be (attended/unattended).

Reaction times exceeding 999 msec were excluded.

Results

Mean reaction times to stimuli presented to the right or the left ear (i) when attention was not directed and (ii) when attention was directed are given in Table 12. Data for individual subjects are given in Appendix 6.1 and 6.2.

An analysis of variance was carried out on the data. There was a significant difference between ears ($F(1,12) = 40.52$, $p<.001$) with faster reaction times to right ear stimuli. This is to be expected since only the data from subjects showing a right ear advantage were used in the analysis. There was a significant effect of attentional condition, reaction time being faster when attention was directed than when it was not ($F(1,12) = 14.65$, $.01>p>.001$). In addition, the interaction: ear advantage x attentional condition was significant ($F(1,12) = 6.88$, $.05>p>.01$). Further analysis of this interaction showed that reaction times for the right ear in Condition 2 (directed attention) did not differ significantly from reaction

Table 12

Table showing mean reaction times (msec) when:
(i) attention was not directed;
(ii) attention was directed to either the right or the left ear;

for (a) each ear
(b) each hand x ear combination;
(c) each sex x ear combination.

	Attention not directed Left Ear	Right Ear	Attention directed Left Ear	Right Ear
(a) Mean reaction time for each ear (N=16)	452.1	352.9	372.5	324.2
(b) Mean reaction time for each hand x ear combination:				
right hand (N=8)	444.0	334.3	374.0	329.0
left hand (N=8)	460.1	371.5	371.0	319.4
(c) Mean reaction time for each sex x ear combination:				
Male subjects (N=8)	449.1	345.9	380.3	328.1
Female subjects (N=8)	455.0	359.9	364.7	320.2

times in Condition 1 (attention not directed) ($F(1,24) = 2.8$, n.s.). **Reaction times to left ear inputs improved** significantly in Condition 2 ($F(1,24) = 21.5$, $p<.001$). The significant difference between ears in Condition 1 ($F(1,24) = 43.1$, $p<.001$) was maintained in Condition 2 ($F(1,24) = 10.3$, $.01>p>.001$).

No other main effects or interactions reached significance. The summary table for the main analysis is given in Appendix 6.3 and that for the analysis of the interaction in Appendix 6.4.

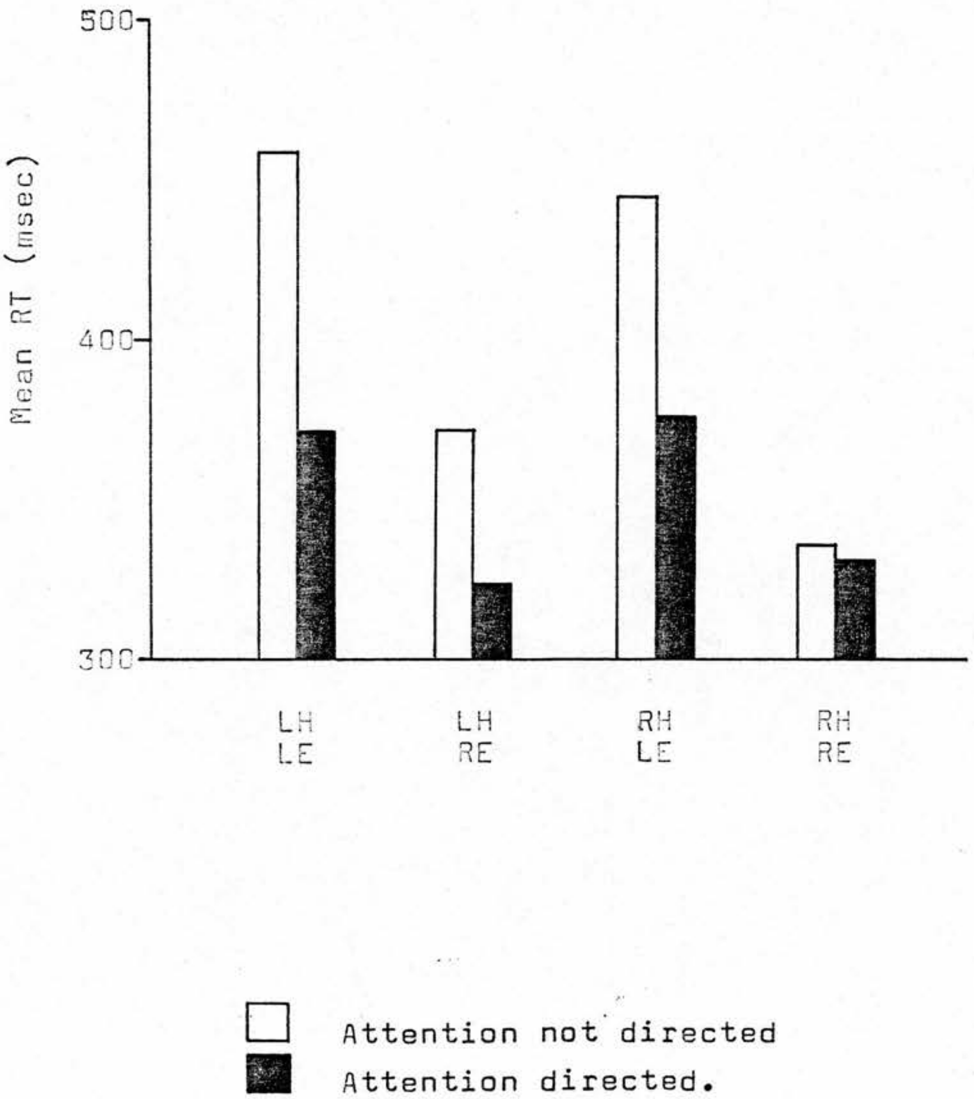
Discussion

Figure 15 shows the mean reaction times for each ear x hand combination in the two attentional conditions. It can be seen that, for the non-directed condition, the fastest reaction time is found for the right ear x right hand relationship and the slowest for the left ear x left hand relationship. The right ear x left hand combination produces faster reaction times than the left ear x right hand combination. This is exactly the same pattern of results as was obtained by Umilta et al (1972) measuring manual reaction times to tachistoscopically presented verbal stimuli (capital letters).

The difference in reaction time in the two conditions is very small for the right ear x right hand combination, only 5.3 msec, compared with 89.1 msec for the left ear x left hand combination. This suggests that there is a very strong bias towards attending to

Figure 15

Histogram showing mean reaction time (msec) in each condition:
(i) attention not directed;
(ii) attention directed to either the right or the left ear;
for each ear x hand combination. (N = 8)



the right ear even in the absence of specific instructions to attend to the right ear, so strong that the additional instruction has a minimal effect.

The apparently greater improvement in reaction time in the right ear x left hand combination compared with the right ear x right hand combination when attention is directed to the right ear could be explained by supposing that the requirement for a left hand response when attention is not directed diverts attention away from the right ear and thus counteracts the natural bias towards attending to the right ear. Only the instruction to attend to the right ear prevents attention from being so diverted.

The statistical analysis confirmed what is suggested by the histogram: that improvement in reaction time to left ear inputs is greater than improvement in reaction time to right ear inputs when attention is directed and that in fact there is no significant improvement in reaction time to right ear inputs when attention is directed to the right ear. That improvement in reaction time would be greater for left ear inputs than for right ear inputs when attention was directed was the result predicted. Although considerable improvement in left ear performance can be elicited by requiring the subject to attend to that ear, left ear performance remains significantly worse than right ear performance.

What the data cannot reveal is whether the relatively greater improvement in left ear performance than in right ear performance in the attended condition is the result merely of the removal of the natural bias towards attending to the right ear or whether the right hemisphere is in any way contributing to the improvement. Experiment 6(ii) endeavours to answer this question.

4. Experiment 6(ii): To examine the effect on manual reaction time of directing attention to the right or the left ear in a dichotic recognition task when a secondary verbal task has to be performed

Introduction

In Experiment 6(i) it was found that reaction time to left ear inputs became significantly faster when attention was directed to the left ear; no significant improvement in reaction time to right ear inputs occurred when attention was directed to the right ear. This result could reflect one of two possible processes: (i) a natural bias towards attending to the right ear which is lessened when subjects are instructed to attend to the left ear; (ii) right hemisphere intervention in processing left ear inputs when attention is directed to the left ear.

Experiment 6(ii) attempts to discover whether the results of Experiment 6(i) only reflect the removal of the natural bias or whether in fact some right hemisphere processing is also occurring. The experiment to be described was similar to Experiment 6(i) in that subjects were instructed to attend to inputs to either the right ear or the left ear. In addition, however, they were required to perform a secondary verbal task, counting in threes.

If the results of Experiment 6(i) arose merely because a natural bias towards attending to the right ear was removed when attention was specifically directed to the left ear, but nevertheless left ear inputs had still to be processed by the left hemisphere, then the performance of a secondary verbal task will affect processing of both left and right ear inputs equally, and this will be reflected in the reaction times. If, however, the right hemisphere does intervene when attention is directed to the left ear then reaction times to left ear inputs will be less affected than reaction times to right ear inputs when a secondary verbal task has to be performed.

Method

Preparation of stimulus material

The tape comprised a modified version of Tape 2 used in Experiment 6(i). The original tape used in Experiment 6(i) consisted of two blocks of 60 pairs of dichotic stimuli, each block containing 20 target stimuli which were presented to the same ear, a total of 40 target stimuli which were presented to the same ear. For that experiment a second version of the tape was also prepared, differing only in randomisation, in order to avoid repetition when the tape was presented to the other ear. The revised tape used in the present experiment comprised two blocks of 44 pairs, 15 of which included the target stimulus 'bel', a total of 30 target stimuli which were presented to the same ear. As in Experiment 6(i) a second version of this tape was constructed so that subjects did not listen to the same tape for every condition and thus memorise any of the word sequences.

Subjects

Subjects were staff and students of Warwick University, right-handed, with no known left-handed relatives and with normal hearing. Subjects were tested until 6 males and 6 females showing a right ear advantage on the control task (attention directed, no secondary task) had been found. Data for one male subject who showed a left ear advantage on the control task are given but were not included in the analysis. Many of the subjects who took part in this experiment had performed in earlier experiments and were selected for this experiment because they had shown a right ear advantage in the past. It is for this reason that only one subject showing a left ear advantage was tested: had the sample been drawn randomly from the population one would have expected a higher proportion of subjects to show a left ear advantage.

Procedure

There were two conditions: Condition (i), the control condition, in which subjects attended either to the right ear or to the left ear and Condition (ii) in which subjects attended either to the right ear or to the left ear and at the same time performed the secondary verbal task.

Subjects were instructed orally to press the response key as quickly as possible after hearing the target stimulus on the attended ear. They were informed that no target stimuli would be presented on the unattended ear. All subjects performed the control task (attention directed, no secondary task) before the secondary task condition, for each ear. Thus a subject would attend, for example, to the right ear and then attend to the right ear while at the same time performing the secondary task. Next he would attend to the left ear and then attend to the left ear and at the same time perform the secondary task.

Subjects listened to Version 1 of the tape for the control task for each ear and to Version 2 for the secondary task condition for each ear. Half the subjects of each sex attended first to the right ear and the other half to the left ear. When attention was directed to the right ear manual response was made by the right index finger and when attention was directed to the left ear the response was made by the left index finger.

For the secondary task subjects were instructed to count to themselves in threes from a given number, either 2, 3 or 4, and were asked at the end of the practice trials and at the end of each of the blocks how far they had counted. Subjects commenced counting from the number 2 for the practice trials and for the first block, and from the number 3 for the second block. When they had to attend to the other ear they began counting from the number 4 for the practice trials and for the first block and from the number 2 for the second block.

12 practice trials were given before each condition for either ear. Two-minute rest pauses were given between blocks and between conditions.

Reaction times exceeding 999 msec were excluded.

Results

Mean reaction times for each ear in each condition are given in Table 13. Data for individual subjects are given in Appendix 6.5 and 6.6.

An analysis of variance was carried out on the data. This revealed a significant difference between ears ($F(1,10) = 48.4$, $p<.001$), which would be expected since the analysis is based only on the data from subjects showing a right ear advantage. There was also a significant difference in speed of reaction time between the two conditions, reaction times being significantly slower when the secondary task had to be performed ($F(1,10) = 67.4$, $p<.001$). No other main effects or interactions were significant. The summary table for this analysis is given in Appendix 6.7.

Discussion

The data show that reaction times to both left and right ear input are equally affected by the performance of a secondary verbal task. It thus appears that even when attention is directed to the left ear, a left hand response is required and the left hemisphere

Table 13

Table showing mean reaction time (msec) for each ear in the two conditions: (i) with no secondary task; (ii) with secondary task. (N=12)

	Left Ear	Right Ear
No secondary task	350.3	285.4
With secondary task	537.8	484.0

is occupied with a secondary verbal task, it is still the left hemisphere which processes left ear input. The results found in Experiment 6(i) of a significantly greater improvement in reaction time to left ear inputs than to right ear inputs when attention was directed must therefore arise solely because when attention is directed to the left ear the natural bias towards attending to the right ear is counteracted: there is no evidence that the right hemisphere intervenes in the processing in this situation.

The data from this experiment do not support the finding in Experiment 5 that performance by female subjects on the dichotic listening task was more strongly affected than performance by male subjects by the presence of the secondary task. In the present experiment there was no significant difference in speed of reaction time between the sexes when a secondary task had to be performed. This outcome may be the result of the changed task requirements in this experiment i.e. that attention was directed while the secondary task had to be performed whereas in Experiment 5 attention was not directed. It is conceiveable that directing attention lessens the processing capacity required to perform the dichotic listening task and thus enables the secondary task to be performed as well without overloading the processor. In Experiment 5, where attention was not directed, this overload could have significantly increased reaction time on the dichotic listening task in females by comparison with males. Alternatively the failure to confirm this result from Experiment 5 might indicate sampling error in Experiment 5.

Chapter 5

1. A review of the main findings

All six experiments made use of the dichotic listening technique and endeavoured to manipulate the task conditions so that any right hemisphere ability to process speech inputs might be revealed. The hypotheses being tested in each experiment and the results obtained are reviewed below.

Experiment 1 : To examine the relationship between magnitude of right ear advantage and amount of practice.

The first experiment tested the hypotheses that with practice and with a non-verbal means of expression, i.e. a manual response, reaction times to left ear inputs would decrease faster than reaction times to right ear inputs, as the right hemisphere intervened in processing left ear inputs and initiating the non-verbal response. The most significant improvement in reaction time was predicted for the left ear x left hand condition since, with right hemisphere intervention, this pathway would become considerably reduced in length, by short circuiting the left hemisphere and thus eliminating two callosal crossings.

The experiment failed to confirm the hypothesis and failed even to elicit a significant right ear advantage. It was suggested that the absence of REA came about because of the high percentage of female subjects, compared with males, who showed a left ear advantage. The only way to confirm this suggestion and to test adequately the original hypothesis was to repeat the experiment using equal numbers of male and female subjects. This was done in Experiment 2.

Experiment 2 : To examine the relationship between magnitude of right ear advantage and amount of practice and to investigate sex differences in direction of ear advantage.

Experiment 2 was similar to Experiment 1, the most important difference being that equal numbers of male and female subjects were used. This experiment revealed a significant right ear advantage and also a significant ear x practice interaction. However, interpretation of this interaction was difficult because, although there was a significant right ear advantage in Session 1 and no significant right ear advantage in Session 2, which would tend to support the prediction, a significant right ear advantage reappeared in Session 3 and 4 (in male subjects only) : this was not predicted. Furthermore, differences in reaction time between the two hands were an integral part of the model and the absence of any such differences adds further difficulty to the interpretation of the data.

Experiment 2 confirmed to some extent the trend shown in Experiment 1 towards LEA in females in that in this experiment as well a higher percentage of females than of males showed a left ear advantage, but this effect did not reach significance. That such a trend appeared in both experiments, although achieving significance in neither, suggests that a slightly greater number of females than males do reliably show a left ear advantage in these conditions.

The relatively high percentage of females showing LEA in this experiment contrasts with the results of earlier work by the present author (Perera 1971) in which, using a dichotic recall task, only one subject out of sixteen female subjects showed LEA. The discrepancy between the latter result and the data from the two experiments so far reported here prompted Experiment 3.

Experiment 3 : To examine the direction of ear advantage in males and females in response to differing task requirements.

Experiment 3 examined the magnitude and direction of ear advantage in four different conditions: (i) a manual reaction time task to dichotic stimuli, comparable to Experiments 1 and 2 already reported; (ii) a dichotic recall task similar to that described by Perera (1971). Comparison of the results obtained in these two conditions, in which each subject performed both tasks, would allow confirmation of the observation that a higher percentage of subjects show LEA in a dichotic recognition task, with manual response, than in a dichotic recall task. The third and fourth conditions were both reaction time tasks to dichotic stimuli but measured verbal response speed rather than manual response speed. If the difference in direction of ear advantage between a recognition task and a recall task lay only in the requirement for a verbal response in the latter case, then the pattern of ear asymmetry in the verbal recognition tasks would be similar to that shown for the recall task. If, on the other hand, the pattern of asymmetry in the verbal recognition tasks did not resemble that shown in the recall task then clearly some other factor must underlie the difference.

The experiment confirmed the earlier observations: of nine subjects who showed LEA on the manual recognition task only two showed LEA on the recall task. However, six of these nine subjects showed a left ear advantage in the verbal recognition task where the response was repetition of the target stimulus 'bel'. Clearly then the difference between the manual recognition task and the recall task did not lie simply in the requirement for a verbal response. It was suggested that in these individuals the right hemisphere was able to program the response 'bel'.

Experiment 3 failed to confirm the trend shown in Experiments 1 and 2 towards a difference in direction of ear advantage between males and females. It was thought that this could have come about because of a change in the task requirements, namely that response was required to only one target stimulus rather than to any one of six target stimuli in Experiments 1 and 2. Experiment 4 tested this possibility.

Experiment 4 : To examine the magnitude and direction of ear advantage in males and females in two tasks with different processing demands.

Experiment 4 sought to discover whether it was in fact a difference in the nature of the two manual recognition tasks which led to the disappearance of any trend towards a sex difference in Experiment 3 compared with the first two experiments or whether sampling error, either in Experiments 1 and 2 or in the third experiment, was responsible for the discrepancy.

Experiment 4 did not reveal any significant difference between males and females in direction or magnitude of ear advantage, neither was there any significant difference between the two tasks in the pattern of asymmetry elicited. Clearly neither the sex of the subject nor the demands of the tasks affected the distribution of cerebral activity between the hemispheres.

Experiment 5 : To examine the effect of a secondary verbal task on dichotic listening performance.

The prediction underlying this experiment was that if a secondary verbal task had to be performed, preoccupying the left hemisphere, the right hemisphere might intervene and process left ear inputs and initiate a manual response and as a result reaction times to left ear inputs would not suffer to the same extent as reaction times to right ear inputs in the presence of a secondary task, since only the right ear inputs would have to compete with the secondary task for processing space. If, on the other hand, reaction times increased to the same extent for response to input to both ears it would suggest that the left hemisphere was processing both right and left ear inputs and that there was no right hemisphere intervention.

The results favoured the second alternative: reaction times to inputs to both ears were equally affected by the presence of the secondary task and thus it appears that the left hemisphere continued to process inputs to both right and left ears while at the same time performing the secondary task. There was no evidence of right hemisphere intervention.

Experiment 6(i) : To examine the effect on manual reaction time of directing attention to the right or left ear in a dichotic listening task.

The purpose of this experiment was to eliminate any natural bias towards attending to the right by directing attention to either the right ear input or to the left ear input. Again the required response was manual rather than verbal in order to give the right hemisphere every opportunity to express itself. It was predicted that reaction times would decrease in the attended condition compared with reaction times in the unattended condition and that this effect would be greater for the left ear than for the right.

The data confirmed this hypothesis - directing attention to the right ear led to no significant improvement whereas directing attention to the left ear did result in a significant decrease in reaction time. What the data could not reveal was whether this outcome arose solely because a natural bias to the right had been overcome or because, with the removal of this bias, the right hemisphere intervened in processing left ear inputs. Experiment 6(ii) sought to clarify this issue.

Experiment 6(ii) : To examine the effect on manual reaction time of directing attention to the right or the left ear in a dichotic recognition task when a secondary verbal task has to be performed.

This experiment was similar to the previous one except that a secondary verbal task had to be performed in addition to the primary task. If in Experiment 6(i) only the left hemisphere was processing inputs to both ears when attention was directed then the performance of a secondary task, occupying the left hemisphere, would interfere equally with processing for both ears and consequently reaction times to inputs at both ears would increase equally. If, however, the right hemisphere was processing left ear inputs then the performance of a concurrent, left hemisphere, task would have less effect on reaction times to left ear inputs than on reaction times to right ear inputs.

The results of this experiment supported the first explanation: reaction times to both right and left ear inputs were equally affected by the performance of the secondary verbal task, suggesting no right hemisphere intervention.

2. The speech processing ability of the right hemisphere

All the experiments described here endeavoured to provide conditions under which any right hemisphere speech processing ability would be demonstrated. In general terms this was achieved either by trying to facilitate right hemisphere intervention by the use of practice (Experiments 1 and 2) or by trying to occupy the left hemisphere (Experiments 5 and 6(ii)) or by overloading the left hemisphere (Experiments 5 and 6(ii)), and also by providing a manual rather than a verbal means of expression, in the hope that the right hemisphere might then be able to express itself independently. In addition a number of other task factors were varied (Experiments 3, 4 and 6(i)(ii)) in order to examine the effect on the size of ear advantage.

It appears that none of these manipulations was sufficient to elicit the latent speech processing ability of the right hemisphere or, alternatively, that the right hemisphere was quite unable to undertake the processing required. The only exception to this was shown in Experiment 3, where some individuals who showed a right ear advantage on a dichotic recall test showed a left ear advantage on the recognition task involving a manual response and also a left ear advantage when the response was verbal - 'bel'. This strongly suggests that in these individuals, who are apparently left hemisphere dominant for speech the right hemisphere <u>was</u> able to process the input and to initiate both a manual and a verbal response.

However, considering all the experiments for the majority of individuals, who showed a right ear advantage when a manual response was required, there was no evidence that any change in the task requirements could elicit right hemisphere participation such that a change in the pattern of asymmetry could be seen.

In this respect the results of Experiment 5 reported here differ from the results obtained by other workers (Geffen et al 1973; Hellige et al 1979) who found that with the use of a concurrent verbal task, presumably occupying the left hemisphere, a reversal of the normal pattern of asymmetry for verbal input could be demonstrated. It seems reasonable to conclude that the experiment reported here differed crucially from their work in that the primary input here was auditory rather than visual and that while the right hemisphere was able to process the visual input in their experiments it was unable to process the auditory input in Experiment 5. This does not mean necessarily that the right hemisphere is unable to process all auditory verbal input but that it was certainly unable to cope with the stimuli used in this experiment, although the fact that the size of ear advantage for 6 target words and for 1 target word does not differ significantly

(Experiment 4) suggests that there is nothing intrinsically exceptional about the stimuli used here.

It could be argued that far from failing to demonstrate right hemisphere mediation the right hemisphere was in fact processing left ear inputs in all these experiments and that the slower reaction time, by comparison with reaction time to right ear inputs, reflects slower processing in the right hemisphere and not transcallosal crossing time. If that were the case then in Experiments 5 and 6(ii), involving performance of a secondary verbal task, reaction times to left ear inputs should have been unaffected by the performance of the secondary task. In fact reaction times to inputs to both ears were equally affected, suggesting that both inputs were being processed by the same mechanism that was carrying out the secondary task, i.e. a left hemisphere mechanism.

One is tempted to conclude on the basis of these experiments that the apparent comprehension shown by brain-damaged subjects for auditory speech input must be based on the high redundancy of the speech input presented to them and that the proposed right hemisphere speech processor which, although functioning on a different basis from that of the left hemisphere, is equally capable of decoding speech input, does not exist. The only alternative to this is to conclude that right hemisphere speech processing only occurs when that hemisphere is physically isolated from the left hemisphere and that otherwise the left hemisphere has control of either input processing or of response or of both. In the absence of the left hemisphere some right hemisphere mechanism, perhaps utilising the usual processing mode of the right hemisphere, can come into operation. A modified version of this idea might be that while right hemisphere speech processing has only been demonstrated in the physical absence of the left hemisphere nevertheless such processing does occur in the normal case, since it seems unlikely that such a system would only function in the rare event of brain trauma. One is then again confronted by the problem of how to demonstrate this ability. The dichotic listening technique, some form of left hemisphere distraction and a readily available manual response still appear in principle to be a useful form of probe for right hemisphere speech processing ability, unless it is the case that the right hemisphere cannot deal with single speech items but can only extract meaning from longer utterances with high redundancy and a wide range of prosodic and contextual cues.

3. Sex differences in asymmetry

Experiments 1 and 2 both revealed a slight trend towards a sex difference in direction of asymmetry: more males than females displayed a right ear advantage. It was suggested that a proportion of females employed a right hemisphere strategy in performing this task (a strategy which, incidentally, was less efficient than a left hemisphere strategy, in this case, since reaction times for these individuals were slower than for those showing REA : left ear reaction times were comparable for the two groups, right ear reaction times for the LEA group were significantly slower than their left ear reaction times).

None of the subsequent experiments confirmed this trend towards a sex difference although a lurking suspicion remains that, if there is a slight bias, it is towards the slightly higher probability that a female will show LEA than that a male will show LEA. This was the case in several of these experiments.

4. Attentional bias

Experiment 6(i) compared reaction times when attention was not explicitly directed to either ear with reaction times when attention was so directed. As predicted reaction times to left ear inputs improved significantly compared with reaction times to right ear inputs in the attended condition. What had not been predicted was the strength of the bias towards attending to the right ear that exists in the absence of specific instructions to attend to the right ear - reaction times for the right ear x right hand combination improved by only 5.3 msec (not significant) when attention was directed, compared with much larger improvements for the other ear x hand combinations.

5. Conclusion

The experiments described here attempted to demonstrate that the right hemisphere of normal right-handed individuals is able to process speech : such an ability is suggested by the split-brain and hemispherectomy literature but has not so far been shown in individuals who are not in some way brain-damaged.

The results of these experiments strongly suggest that the right hemisphere is unable to process single word speech inputs of the kind used here (but see Experiment 3 where certain individuals did show a left ear advantage for these stimuli). This does not imply that the right hemisphere is unable to process speech but that it cannot process units of the size used here and indeed where ability to process speech has been shown in the clinical literature the input has involved meaningful sequences of several words rather than single words. On the other hand, reports from both split-brain and normal subjects suggest that the right hemisphere can process single word verbal inputs when these are presented visually and it thus appears that these inputs to the right hemisphere have access to a verbal processing system to which single word auditory input to the right hemisphere does not.

These results, then, do not conflict with the clinical evidence but do suggest that the right hemisphere in right-handed individuals is unable to process single word speech input.

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Appendices

Notes

1. Analysis of variance procedures follow Kirk (1968).

2. Values of F for which no level of significance is given failed to reach significance at the 5% level.

3. Figures given for the standard deviation refer to the estimate of the standard deviation of the population, defined as : $\sqrt{x^2 / n-1}$, rather than to the sample standard deviation, $\sqrt{x^2 / n}$, since the former provides a closer approximation to the population standard deviation than does the sample standard deviation.

Experiment 1

Data for individual subjects.

Mean reaction time (msec) for each hand/ear combination for each session.

* indicates left ear advantage in a given session. M/F = Male/Female.

Right Hand Response

		Session 1		Session 2		Session 3		Session 4	
		Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
F	1.	1261.2	1209.8	1343.4	1324.4	1218.8	1198.9	1242.8	1327.5*
F	2.	880.4	1058.2*	969.7	992.6*	862.8	1037.8*	1008.6	1101.5*
M	3.	984.2	850.4	1103.0	1052.4	1024.3	827.7	903.3	875.1
F	4.	898.8	943.6*	1002.3	1058.9*	967.0	907.0	1007.0	1069.5*
F	5.	881.1	902.5*	910.6	1018.2*	896.4	902.9*	883.6	1017.2*
M	6.	1090.2	959.1	1063.7	1037.0	1149.7	1222.0*	1345.7	1351.5*
F	7.	807.9	953.6*	890.2	818.4	796.7	902.7*	770.5	760.0
F	8.	1026.2	1012.4	855.8	952.6*	936.8	994.5*	842.5	906.7*
F	9.	961.7	910.4	953.1	858.4	1023.6	959.6	1011.5	899.1
F	10.	809.4	827.3*	789.8	687.7	708.1	695.1	705.2	601.3
F	11.	996.5	1024.4*	1136.9	1030.0	1043.3	878.3	1103.7	921.5
F	12.	1071.3	937.5	1019.3	882.2	998.7	880.5	945.7	835.7
	$\bar{x}$	972.4	965.8	1003.2	976.1	968.9	950.6	980.8	972.2

Experiment 1

Data for individual subjects.

Mean reaction time (msec) for each hand/ear combination for each session.

* indicates left ear advantage in a given session. M/F = Male/Female.

Left Hand Response

		Session 1		Session 2		Session 3		Session 4	
		Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
F	1.	926.8	837.3	942.5	950.5*	943.3	817.5	1074.7	989.7
F	2.	1042.3	870.4	973.9	928.7	975.1	787.3	994.2	902.1
F	3.	1223.4	1125.0	1116.9	1013.7	1035.3	1022.0	1107.9	958.4
M	4.	1213.5	1158.3	1221.4	1195.1	1119.1	1125.1*	1034.7	965.3
M	5.	812.9	743.0	708.7	658.5	755.0	694.9	721.4	645.2
F	6.	862.3	790.6	900.7	876.3	828.5	768.8	925.9	898.7
M	7.	979.2	960.8	860.3	853.1	743.1	792.3*	789.7	796.8*
F	8.	649.9	802.6*	563.0	731.9*	682.0	763.2*	603.5	750.1*
F	9.	832.5	879.1*	828.4	828.4	846.9	803.8	819.2	841.0*
F	10.	1243.0	1270.4*	1217.8	1329.1*	1249.4	1394.0*	1187.5	1358.7*
M	11.	1123.6	1091.7	1177.7	1083.4	1090.0	945.8	1204.1	1035.4
M	12.	787.8	700.6	663.2	627.3	719.0	706.3	682.1	690.9*
	$\bar{x}$	974.8	935.8	931.2	923.0	915.6	885.1	928.7	902.7

Experiment 1

Data for individual subjects, showing:

(i) Standard deviation (SD) of mean reaction time (msec) for each hand/ear combination for each session;

(ii) number of responses (N) upon which mean and standard deviation are based (maximum possible number of responses for each entry = 42).

Right Hand Response

	Session 1				Session 2				Session 3				Session 4			
	Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear	
	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N
1.	281.8	38	250.9	32	241.5	35	304.5	28	298.7	37	356.6	34	221.4	40	334.4	35
2.	257.1	38	263.8	38	250.8	40	191.2	39	255.2	37	235.5	41	331.0	38	323.0	41
3.	273.8	41	315.7	37	332.1	39	335.7	42	346.7	42	262.7	40	195.9	41	284.3	42
4.	244.8	40	253.1	41	248.0	37	249.5	40	210.0	38	217.3	40	168.8	38	241.9	40
5.	275.6	36	255.2	35	247.0	37	272.7	38	310.0	38	291.6	36	270.5	36	291.2	37
6.	339.1	36	288.6	36	295.2	40	236.8	39	239.7	36	385.4	40	346.3	37	310.7	35
7.	239.5	42	315.5	41	302.1	38	266.6	41	188.7	40	272.4	39	195.4	40	241.5	42
8.	275.9	42	260.6	42	210.2	41	253.6	40	193.4	41	207.4	42	233.4	41	259.2	39
9.	248.2	40	275.4	40	294.5	39	280.3	39	233.4	39	253.6	38	324.2	36	206.1	37
10.	306.6	39	295.5	42	280.5	33	241.1	42	239.9	39	253.9	42	299.6	37	189.5	42
11.	249.9	34	413.4	36	419.1	32	386.4	31	232.8	40	320.3	35	416.0	40	349.1	37
12.	250.5	41	328.8	41	291.1	38	287.1	41	225.6	40	243.0	40	216.0	35	302.7	41

Experiment 1

Data for individual subjects, showing:

(i) Standard deviation (SD) of mean reaction time (msec) for each hand/ear combination for each session;

(ii) number of responses (N) upon which mean and standard deviation are based (maximum possible number of responses for each entry = 42).

Left Hand Response

	Session 1				Session 2				Session 3				Session 4			
	Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear	
	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N
1.	246.5	39	200.7	42	190.7	38	202.5	40	195.4	37	146.0	42	281.6	37	263.9	39
2.	343.8	35	197.4	39	314.0	38	285.0	37	327.5	37	224.5	41	274.1	39	297.3	40
3.	311.1	35	267.4	37	242.2	40	259.5	39	186.9	38	252.6	40	252.4	40	282.3	42
4.	287.0	38	315.0	33	327.8	32	368.8	33	307.8	39	329.4	36	333.6	40	275.4	40
5.	293.3	40	262.1	40	214.5	41	227.9	41	261.2	39	165.3	40	266.7	41	184.1	42
6.	303.0	38	231.2	36	334.6	41	260.1	40	324.9	40	300.8	37	331.0	39	354.2	39
7.	309.1	37	299.9	36	309.7	35	263.9	37	218.3	37	281.0	40	244.6	40	265.0	39
8.	200.3	41	290.9	41	134.2	39	276.0	41	257.5	42	220.6	41	158.6	40	271.0	42
9.	273.6	39	243.8	40	293.2	40	218.4	40	308.4	38	183.9	40	278.2	41	226.5	42
10.	216.2	40	297.3	34	323.0	36	358.0	34	305.4	40	268.6	38	320.8	40	246.6	39
11.	364.9	38	301.3	35	364.2	32	353.5	33	260.6	35	253.4	37	338.5	23	356.3	30
12.	228.2	42	276.2	39	172.3	38	209.3	40	236.6	41	264.9	42	192.7	38	197.1	39

Experiment 1 Appendix 1.3

Analysis of variance table showing effects of hand used to make the response (A), ear to which the target stimulus was presented (B) and amount of practice (C).

Source	SS	df	MS	F
Between subjects	4844072.2	23		
A (Hand)	115846.6	1	115846.6	0.5
Subj w.groups	4728225.6	22	214919.4	
Within subjects	1005379.4	168		
B (Ear)	20245.9	1	20245.9	1.6
AB	1391.0	1	1391.0	0.1
B x subj w.groups	281716.5	22	12805.3	
C (Practice)	30237.7	3	10079.2	1.3
AC	20030.8	3	6676.9	0.8
C x subj w.groups	529315.9	66	8019.9	
BC	460.7	3	153.6	0.1
ABC	4167.4	3	1389.1	0.8
BC x subj w.groups	117813.5	66	1785.1	
Total	5849451.6	191		

Analysis of variance table based on mean reaction time over all four sessions, showing effects of two variables, sex of subject (A) and ear to which target stimulus was presented (B).

Source	SS	df	MS	F
A (Sex)	1221.0	1	1221.0	0.02
Subj w.groups	1209871.4	22	54994.2	
B (Ear)	8673.0	1	8673.0	2.88
AB	4601.0	1	4601.0	1.53
B x subj w.groups	66239.7	22	3010.9	

Appendix 2.1

Experiment 2

Data for individual Subjects.

Mean reaction time (msec) for each hand/ear combination for each session.

Male Subjects

Right Hand Response

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
1.	917.9	769.2	841.3	784.4	837.8	829.9	851.3	753.9
2.	930.8	884.3	862.7	857.3	903.7	919.9*	933.1	901.8
3.	969.3	1068.1*	961.3	958.0	1038.5	988.7	1087.4	1087.3
4.	1139.0	1180.7*	873.6	1042.9*	1031.7	1101.0*	997.1	998.6*
5.	853.0	787.8	819.2	847.7*	875.9	738.5	964.0	757.9
6.	877.0	727.7	916.6	722.0	830.0	655.9	838.6	761.0
7.	809.3	743.6	811.4	704.1	917.1	764.6	813.9	669.6
8.	1062.8	1023.2	958.6	1015.7*	1078.6	905.9	1023.9	949.4
9.	1155.0	1088.1	968.9	992.3*	968.0	1011.9*	1013.0	989.5
10.	911.6	769.4	818.4	774.7	824.1	764.8	764.3	742.6
11.	779.7	779.7	694.6	740.9*	788.7	755.9	746.8	778.5*
12.	870.5	868.5	774.9	837.1*	880.8	869.3	831.5	775.2
$\bar{x}$	939.7	890.9	858.5	856.4	914.6	858.9	905.4	847.1

Appendix 2.1 (contd)

Male Subjects

Left Hand Response

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
1.	727.9	716.5	862.8	816.9	820.3	786.3	981.0	846.3
2.	904.2	857.5	723.4	617.7	712.9	718.3*	645.4	550.9
3.	875.8	780.0	763.1	645.9	706.7	539.2	759.7	660.6
4.	873.7	865.3	851.1	826.8	855.5	893.7*	864.0	853.8
5.	1086.2	1049.1	934.6	932.5	908.6	849.2	980.9	883.5
6.	956.9	930.8	874.5	978.8*	776.3	815.8*	803.6	829.9*
7.	710.1	704.6	713.6	699.6	873.9	781.4	725.5	729.6*
8.	1013.4	1127.1*	1008.7	1119.5*	1035.0	1070.8*	1078.5	1016.3
9.	783.3	789.5*	845.9	848.2*	823.9	838.9*	892.2	749.7
10.	1172.4	901.7	1057.4	1012.2	1035.9	880.8	1160.7	1088.0
11.	1042.8	1015.9	1132.0	1111.1	1142.0	1078.6	1121.4	1089.9
12.	988.9	913.4	983.3	924.0	1026.1	960.7	1126.1	1030.8
$\bar{x}$	928.0	887.6	895.9	877.8	893.1	851.1	928.3	860.8

Appendix 2.1 (contd)

Female Subjects

Right Hand Response

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
1.	934.6	896.0	1033.0	954.5	1009.0	912.8	1013.1	988.7
2.	1139.9	1156.3*	1053.2	1086.6*	1041.1	1084.4*	1023.6	1052.4*
3.	969.2	920.9	1015.0	911.9	884.9	821.4	946.0	887.2
4.	789.5	799.9*	760.1	877.6*	715.6	802.1*	760.9	954.3*
5.	942.8	884.2	1073.0	1084.1*	1179.6	1090.2	1164.2	1189.1*
6.	649.4	828.7*	703.9	795.6*	694.7	871.0*	695.3	837.1*
7.	971.6	895.3	964.1	943.1	924.1	985.3*	949.4	966.9*
8.	925.4	700.1	876.5	733.7	964.5	699.4	849.9	663.1
9.	905.7	795.8	855.2	742.2	853.2	767.4	835.5	758.9
10.	1015.8	1079.8*	1006.0	1001.1	920.3	982.1*	1004.6	971.8
11.	973.8	953.8	913.2	951.4*	965.6	1104.6*	905.9	936.4*
12.	926.8	822.1	917.2	1023.6*	1025.6	926.9	975.1	861.7
$\bar{x}$	928.7	894.4	930.9	925.5	931.5	920.6	927.0	922.3

Appendix 2.1 (contd)

Female Subjects

Left Hand Response

	Session 1		Session 2		Session 3		Session 4	
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear
1.	987.5	1024.3*	953.0	1119.3*	1110.5	1126.1*	1236.5	1189.3
2.	1043.8	951.6	875.6	862.7	941.4	853.8	933.7	884.3
3.	855.6	743.1	696.1	619.1	643.0	552.0	642.0	610.7
4.	1017.0	1056.3*	938.3	939.4*	922.3	880.5	947.4	910.6
5.	900.5	809.5	883.0	794.7	870.4	777.1	798.1	767.8
6.	724.8	636.5	684.1	717.9*	704.8	832.7	730.2	689.3
7.	942.9	1002.9*	966.1	1044.7*	947.4	1018.6*	793.1	842.0*
8.	754.1	890.5*	724.0	793.2*	795.5	904.7*	740.4	864.9*
9.	944.9	792.1	875.1	882.6*	936.6	844.6	942.4	934.7
10.	936.3	879.8	1011.7	884.3	856.4	944.9*	977.3	986.9*
11.	899.5	914.1*	926.7	1043.4*	943.9	939.7	994.1	1090.1*
12.	941.9	843.9	845.1	759.8	841.4	782.1	814.4	800.1
$\bar{x}$	912.4	878.7	864.9	871.8	876.1	854.7	879.1	880.9

Experiment 2

Data for individual subjects, showing:

(i) Standard deviation (SD) of mean reaction time (msec) for each hand/ear for each session;

(ii) number of responses (N) upon which mean and standard deviation are based (maximum possible number of responses for each entry = 36).

Male Subjects

Right Hand Response

	Session 1				Session 2				Session 3				Session 4			
	Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear	
	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N
1.	348.8	29	244.1	28	313.5	34	217.4	34	288.2	36	252.1	33	213.7	36	207.3	35
2.	303.5	33	298.5	36	255.3	34	344.5	32	240.0	33	349.8	36	313.3	34	300.0	32
3.	298.3	32	283.3	33	308.5	33	238.9	36	338.0	36	283.9	36	285.1	34	260.5	36
4.	277.3	26	286.8	31	206.9	33	303.7	33	317.0	29	339.2	33	345.8	34	227.0	34
5.	277.8	34	235.7	36	255.9	35	299.1	35	315.0	35	240.7	34	309.5	35	216.2	35
6.	312.9	33	225.6	36	250.3	35	266.8	33	257.6	34	259.5	36	196.0	35	287.9	34
7.	214.4	29	259.7	28	239.0	31	274.6	34	320.7	35	278.9	33	251.6	35	176.1	35
8.	289.9	32	364.4	33	290.3	33	309.9	31	318.1	34	241.1	34	314.0	36	272.3	34
9.	303.3	32	284.2	28	271.9	32	323.8	33	204.8	35	227.9	34	227.9	35	252.2	32
10.	334.6	36	234.4	34	261.8	36	264.3	32	277.1	36	213.8	36	290.2	35	214.3	34
11.	308.1	32	232.9	33	193.0	30	247.7	32	238.3	33	226.6	36	276.7	33	218.3	34
12.	234.2	33	225.1	25	176.4	35	213.3	35	249.9	34	242.5	34	227.8	35	230.2	34

Appendix 2.2 (contd)

Male Subjects

Left Hand Response

	Session 1				Session 2				Session 3				Session 4			
	Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear	
	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N
1.	261.4	32	284.3	34	296.8	30	370.2	34	226.2	34	321.8	35	327.1	33	329.1	31
2.	363.6	30	369.6	31	203.2	34	274.8	33	291.3	31	354.3	35	233.3	35	255.2	36
3.	272.4	26	267.9	32	316.3	30	238.5	33	294.6	31	182.4	34	327.4	35	259.4	36
4.	364.0	31	341.9	30	331.7	32	265.7	32	333.3	34	377.7	35	293.6	32	280.9	34
5.	396.8	33	388.8	33	358.7	32	291.7	34	329.4	36	298.4	33	334.2	35	265.5	35
6.	360.6	36	290.5	36	298.2	35	333.4	36	261.4	36	228.5	35	277.1	36	261.5	35
7.	274.8	24	178.5	32	203.6	29	179.2	31	272.8	32	253.1	35	189.0	33	135.0	34
8.	350.5	30	306.2	35	225.0	28	306.9	32	355.5	25	324.5	33	267.9	33	365.8	26
9.	228.5	35	240.0	32	209.5	34	282.8	34	185.1	34	322.4	35	262.7	34	190.9	35
10.	342.8	29	269.1	26	353.1	32	392.2	32	298.7	30	277.3	29	309.1	28	360.8	34
11.	337.4	31	307.7	35	253.4	34	290.4	34	325.4	32	221.8	31	282.6	33	270.6	33
12.	259.8	29	203.3	31	267.4	32	276.3	32	252.6	32	338.0	34	309.2	30	257.1	31

Appendix 2.2 (contd)

Female Subjects

Right Hand Response

	Session 1				Session 2				Session 3				Session 4			
	Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear	
	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N
1.	230.6	32	285.6	35	231.4	31	240.0	35	290.6	33	204.4	35	250.8	28	307.4	33
2.	320.2	31	314.6	25	288.9	34	298.4	34	323.8	33	237.3	35	290.1	31	310.9	33
3.	226.0	34	232.2	36	265.0	36	201.8	36	190.2	35	197.6	36	331.0	36	223.1	36
4.	190.9	35	218.6	35	166.3	36	296.4	35	91.0	35	271.8	35	172.5	35	244.4	35
5.	295.3	29	253.3	33	343.5	22	285.4	30	329.8	25	271.0	33	311.2	25	278.2	29
6.	194.1	32	311.6	32	223.7	32	285.1	33	318.0	36	301.4	34	252.2	36	252.9	36
7.	386.5	32	242.6	33	400.4	33	298.5	34	290.4	34	276.3	32	321.4	31	254.7	34
8.	250.9	30	260.7	35	214.3	35	291.4	36	250.8	34	201.9	35	241.6	35	239.5	34
9.	280.0	34	299.7	36	232.8	34	228.2	34	247.9	34	269.3	36	165.4	32	168.1	35
10.	432.1	32	326.9	32	352.0	35	348.0	32	231.7	30	271.3	34	340.3	33	365.0	31
11.	273.8	34	290.5	32	206.3	36	204.7	33	234.3	36	317.3	33	175.0	35	178.6	35
12.	293.3	29	265.6	34	240.2	34	338.6	34	298.1	35	256.9	35	332.9	35	244.1	35

Female Subjects

Left Hand Response

	Session 1				Session 2				Session 3				Session 4			
	Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear	
	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N
1.	275.2	33	229.0	36	215.5	34	272.1	35	239.5	35	208.3	35	304.4	29	269.2	35
2.	317.8	36	295.0	34	313.4	32	335.0	35	299.4	34	240.7	34	236.1	34	264.3	36
3.	274.3	33	245.6	33	243.9	35	219.2	35	212.0	34	168.4	35	208.5	34	236.4	35
4.	264.7	31	343.9	33	281.0	36	229.7	33	263.0	34	240.6	34	214.6	34	202.7	34
5.	416.8	30	377.5	31	361.1	33	276.4	36	333.3	36	239.8	35	258.4	35	287.0	36
6.	262.0	34	252.0	35	265.6	34	348.6	34	241.5	35	192.8	36	181.5	33	268.8	35
7.	331.9	24	372.6	28	302.4	36	334.5	34	263.8	29	312.0	30	231.1	33	218.2	32
8.	355.9	35	388.6	35	208.7	36	273.3	32	348.1	35	322.5	36	296.8	34	277.8	34
9.	286.7	35	280.4	35	175.7	33	269.1	34	184.9	34	199.8	34	206.5	33	306.2	34
10.	245.3	32	354.6	29	308.3	32	298.1	34	238.5	34	283.8	36	268.9	32	234.5	33
11.	278.2	30	311.0	24	310.2	32	331.3	32	316.9	35	235.6	27	243.2	35	303.7	34
12.	241.3	36	214.4	33	235.3	35	186.9	36	200.5	36	213.2	36	293.5	35	223.3	34

Experiment 2 Appendix 2.3

Analysis of variance table showing effects of sex of subject (A), ear to which target stimulus was presented (B), hand used to make the response (C) and amount of practice (D).

Source	SS	df	MS	F
Between subjects	5011151.9	47		
A (Sex)	15864.6	1	15864.6	0.1
C (Hand)	36282.0	1	36282.0	0.3
AC	64056.4	1	64056.4	0.6
Subj w.groups	4894948.9	44	111248.8	
Within subjects	1654505.8	336		
B (Ear)	70780.0	1	70780.0	7.1 *
AB	20010.5	1	20010.5	2.0
BC	12.5	1	12.5	
ABC	52.2	1	52.2	
B x subj w.groups	437443.8	44	9941.9	
D (Practice)	28932.8	3	9644.3	1.6
AD	15315.3	3	5105.1	0.8
CD	10724.6	3	3574.9	0.6
ACD	20560.2	3	6853.4	1.1
D x subj w.groups	817575.0	132	6193.8	
BD	16946.8	3	5648.9	3.7 *
ABD	10419.6	3	3473.2	2.3
BCD	159.6	3	53.2	
ABCD	2493.9	3	831.3	
BD x subj w.groups	203079.0	132	1538.5	
Total	6665657.7	383		

* .05>p>.01

Experiment 2 Appendix 2.4

Analysis of ear x practice interaction (BD), showing the level of significance of the difference in reaction time between the ears (B) at each stage of practice (d_1 - d_4).

Source	SS	df	MS	F
Between B at d_1	37036.4	1	37036.4	10.2 *
Between B at d_2	525.0	1	525.0	0.1
Between B at d_3	25331.3	1	25331.3	7.0 *
Between B at d_4	24834.4	1	24834.4	6.8 *
Error		176	3639.4	

* $.01 > p > .001$

Experiment 2 Appendix 2.5

Analysis of variance table based on log. transformed data, showing effects of sex of subject (A) ear to which target stimulus was presented (B), hand used to make the response (C) and amount of practice (D).

Source	SS	df	MS	F
Between subjects	1.3640	47		
A (Sex)	0.0073	1	.0073	
C (Hand)	0.0196	1	.0196	
AC	0.0125	1	.0125	
Subj w.groups	1.3246	44	.0301	
Within subjects	0.4234	336		
B (Ear)	0.0214	1	.0214	7.38 **
AB	0.0054	1	.0054	1.86
BC	0.0001	1	.0001	
ABC	0.0000	1	.0000	
B x subj w.groups	0.1282	44	.0029	
D (Practice)	0.0054	3	.0013	0.87
AD	0.0042	3	.0014	0.93
CD	0.0026	3	.0009	
ACD	0.0045	3	.0015	1.00
D x subj w.groups	0.2008	132	.0015	
BD	0.0025	3	.0008	2.67
ABD	0.0031	3	.0010	3.33 *
BCD	0.0000	3	.0000	
ABCD	0.0007	3	.0002	
BD x subj w.groups	0.0445	132	.0003	
Total	1.7874	383		

* $.05 > p > .01$

** $.01 > p > .001$

Experiment 2 Appendix 2.6

Analysis of variance summary table for sex x ear x practice interaction (ABD) for log. transformed data.

Source	SS	df	MS	F	
Between ears					
Females:					
Session 1	.0038952	1	.0038952	3.970	*
Session 2	.0000642	1	.0000642	.065	
Session 3	.0007704	1	.0007704	.785	
Session 4	.0000287	1	.0000287	.029	
Males:					
Session 1	.0045650	1	.0045650	4.652	*
Session 2	.0012201	1	.0012201	1.243	
Session 3	.0090421	1	.0090421	9.215	**
Session 4	.0127596	1	.0127596	13.003	***
Error		176	.00098125		

* $.05>p>.01$
** $.01>p>.001$
*** $p<.001$

Experiment 2 Appendix 2.7

Analysis of variance table based on the data of the female subjects only, exploring the differences between those subjects showing REA (N=11) and those showing LEA (N=13). The table examines: the speed of response for the two groups (A); whether response to material presented to one ear was faster than response to material presented to the other (B); the difference in speed of response for the right and the left hands (C); the effect of practice (D); as well as all interactions between these variables.

Source	SS	df	MS	F	
Between subjects	2360911.2	23			
A (REA/LEA)	541818.4	1	541818.4	6.50	*
C (Hand)	98378.1	1	98378.1	1.18	
AC	52775.9	1	52775.9		
Subj w.groups	1667938.8	20	83396.9		
Within subjects	825450.3	168			
B (Ear)	7761.0	1	7761.0	1.52	
AB	175681.6	1	175681.6	34.51	**
BC	57.9	1	57.9		
ABC	5945.1	1	5945.1	1.17	
B x subj w.groups	101828.8	20	5091.4		
D (Practice)	1879.5	3	626.5		
AD	20776.7	3	6925.6	1.10	
CD	15664.9	3	5221.6		
ACD	8123.9	3	2708.0		
D x subj w.groups	378630.5	60	6310.5		
BD	9262.3	3	3087.4	2.13	
ABD	6969.5	3	2323.2	1.61	
BCD	850.6	3	283.5		
ABCD	5224.7	3	1741.6	1.20	
BD x subj w.groups	86793.3	60	1446.6		
Total	3186361.5	191			

* .05>p>.01

** p<.001

Analysis of the direction of ear advantage x reaction time interaction (AB) where

A = direction of ear advantage

a_1 = subjects showing Right Ear Advantage (N=11),

a_2 = subjects showing Left Ear Advantage (N=13),

B = reaction time for either ear,

b_1 = left ear

b_2 = right ear

Source	SS	df	MS	F
Between A at b_1	50224.9	1	50224.9	1.1
Between A at b_2	667277.3	1	667277.3	15.1 **
Error		40	44244.2	
Between B at a_1	135515.9	1	135515.9	26.6 **
Between B at a_2	47928.9	1	47928.9	9.4 *
Error		20	5091.4	

* $.01 > p > .001$

** $p < .001$

Data for individual target words, showing:

(i) Standard deviation (SD) of each mean shown in Table 7. Each entry is based on the data for 12 subjects.

(ii) Mean percentage (%) responses for each word for the 12 subjects represented by each entry. The maximum possible number of responses for each word at a given ear for each subject over all four sessions = 24 = 100%, since there were six presentations of each word to each ear over four sessions.

	Male Subjects							
	Right Hand Response				Left Hand Response			
	Left Ear		Right Ear		Left Ear		Right Ear	
	SD	%	SD	%	SD	%	SD	%
LION	98.3	99.7	139.5	99.7	114.9	95.1	128.6	97.2
FULL	179.7	76.7	198.9	75.7	196.1	64.9	181.0	69.8
BRANCH	126.2	93.1	151.8	93.1	151.4	88.2	161.9	94.4
SAIL	139.6	96.5	159.2	95.1	180.5	91.7	178.3	93.1
END	104.1	93.8	161.7	94.8	181.9	92.4	217.3	97.6
SPIDER	120.2	99.0	94.0	99.0	140.8	99.7	160.0	99.3

Data for individual target words, showing:

(i) Standard deviation (SD) of each mean shown in Table 7. Each entry is based on the data for 12 subjects.

(ii) Mean percentage (%) responses for each word for the 12 subjects represented by each entry. The maximum possible number of responses for each word at a given ear for each subject over all four sessions = 24 = 100%, since there were six presentations of each word to each ear over four sessions.

	Female Subjects							
	Right Hand Response				Left Hand Response			
	Left Ear		Right Ear		Left Ear		Right Ear	
	SD	%	SD	%	SD	%	SD	%
LION	119.8	98.6	103.6	99.3	131.1	97.9	161.4	99.3
FULL	167.3	71.5	180.7	79.9	171.5	76.7	229.3	77.1
BRANCH	154.3	90.3	142.0	95.8	121.3	92.0	200.4	90.6
SAIL	122.9	93.1	126.0	93.1	124.1	96.9	119.7	96.9
END	168.0	93.8	153.6	96.5	125.8	95.8	151.3	97.6
SPIDER	106.6	99.3	115.4	99.0	131.4	99.3	132.7	99.7

Experiment 2 Appendix 2.10

Analysis of variance table based on reaction times (msec) to each of the six target stimuli, averaged over all four sessions, showing effects of sex of subject (A), target word (B), hand used for response (C) and ear to which target stimulus was presented (D).

Source	SS	df	MS	F
Between subjects	7909350.1	47		
A (Sex)	13060.7	1	13060.7	
C (Hand)	32764.0	1	32764.0	
AC	121034.4	1	121034.4	
Subj w.groups	7742491.0	44	175965.7	
Within subjects	15170775.1	528		
B (Word)	10280618.6	5	2056123.7	171.2**
AB	34902.8	5	6980.6	
BC	92038.4	5	18407.7	1.5
ABC	80819.9	5	16164.0	
B x subj w.groups	2642911.9	220	12013.2	
D (Ear)	118141.2	1	118141.2	7.4*
AD	27658.4	1	27658.4	
CD	414.8	1	414.8	
ACD	2522.6	1	2522.6	
D x subj w.groups	707481.0	44	16079.1	
BD	77932.3	5	15586.5	3.2*
ABD	11091.6	5	2218.3	
BCD	10365.3	5	2073.1	
ABCD	13520.3	5	2704.1	
BD x subj w.groups	1070356.0	220	4865.3	
Total	23080125.2	575		

* .01>p>.001
** p<.001

Experiment 2 Appendix 2.11

Further analysis of the word x ear (BD) interaction.

Source				
Between ears				
for:				
LION	1401.5	1	1401.5	0.21
FULL	33316.5	1	33316.5	4.95*
BRANCH	13697.1	1	13697.1	2.03
SAIL	16994.8	1	16994.8	2.52
END	130485.9	1	130485.9	19.38**
SPIDER	177.9	1	177.9	0.03
Error		264	6734.3	

* $.05 > p > .01$
** $p < .001$

Experiment 3

Data for individual subjects, showing standard deviations (SD) for each ear for the three recognition tasks and the total number of responses (N) made for each ear, out of a possible total of 40.

Male Subjects

	Task 1				Task 2				Task 3			
	Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear	
	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N
1.	138.8	39	151.8	40	115.4	36	125.1	36	116.5	39	123.4	36
2.	331.6	35	254.7	37	171.6	36	197.0	38	341.0	38	179.9	40
3.	177.7	39	162.0	40	185.4	31	129.5	32	197.9	33	119.9	38
4.	147.9	37	153.9	35	157.5	39	150.9	39	137.7	37	102.3	40
5.	186.1	35	95.3	37	130.1	35	80.0	34	130.8	29	85.1	33
6.	95.1	34	113.6	37	133.8	38	123.3	37	107.4	38	148.7	36
7.	182.1	38	103.2	36	121.8	35	124.6	38	141.8	38	172.8	38
8.	121.7	33	141.8	34	235.0	32	146.7	30	191.1	37	111.3	36
9.	151.0	37	137.4	38	109.5	32	185.5	28	124.9	35	119.8	37
10.	194.8	36	221.6	37	141.3	34	141.3	36	125.3	35	136.8	39
11.	104.0	34	93.4	35	101.5	30	81.5	30	100.2	29	85.6	30
12.	193.3	35	126.6	39	153.3	33	125.2	31	202.4	36	96.2	30

Experiment 3

Data for individual subjects, showing standard deviations (SD) for each ear for the three recognition tasks and the total number of responses (N) made for each ear, out of a possible total of 40.

Female Subjects

	Task 1				Task 2				Task 3			
	Left Ear		Right Ear		Left Ear		Right Ear		Left Ear		Right Ear	
	SD	N	SD	N	SD	N	SD	N	SD	N	SD	N
1.	157.3	39	164.9	35	100.1	36	150.5	39	138.6	36	123.7	36
2.	244.9	39	134.8	39	147.9	39	178.9	39	155.0	39	171.2	40
3.	132.5	39	160.6	37	139.4	40	192.7	35	155.1	40	173.0	40
4.	120.8	38	141.5	37	143.7	38	115.0	40	100.8	40	170.9	35
5.	216.3	38	121.3	37	118.8	37	107.2	36	176.7	39	116.6	30
6.	172.9	38	135.8	39	160.1	31	108.7	36	162.3	38	147.6	33
7.	240.1	37	132.0	38	168.2	35	127.6	39	157.8	32	185.8	39
8.	216.5	36	167.0	35	131.1	29	89.7	32	184.4	35	93.1	35
9.	141.8	38	195.7	36	150.9	34	197.3	38	132.5	38	176.9	39
10.	131.1	35	153.4	39	99.9	40	119.0	40	116.0	37	119.2	36
11.	121.8	38	100.4	36	167.3	26	99.0	30	106.6	37	85.1	37
12.	138.2	34	164.5	37	136.8	29	123.2	36	265.1	25	120.5	35

Experiment 3 Appendix 3.2

Analysis of variance table for recognition tasks 1, 2 and 3, showing effects of sex of subject (A), task (recognition task 1, 2 or 3) (B), and ear to which target stimulus was presented (C).

Source	SS	df	MS	F
Between subjects	1874432.29	23		
A (Sex)	45014.70	1	45014.70	.54
Subj w.groups	1829417.59	22	83155.35	
Within subjects	1299115.37	120		
B (Task)	650956.37	2	325478.19	36.27*
AB	3372.08	2	1686.04	.19
B x subj w.groups	394892.02	44	8974.82	
C (Ear)	75982.92	1	75982.92	15.50*
AC	8372.25	1	8372.25	1.71
C x subj w.groups	107857.60	22	4902.62	
BC	357.33	2	178.67	.14
ABC	701.71	2	350.86	.27
BC x subj w.groups	56623.09	44	1286.89	
Total	3173547.66	143		

* $p<.001$

Experiment 3 Appendix 3.3

Analysis of variance table for the dichotic recall task showing effects of sex of subject (A) and ear from which items were recalled (B).

Source	SS	df	MS	F
Between subjects	552.3	23		
A (Sex)	38.5	1	38.5	1.65
Subj w.groups	513.8	22	23.4	
Within subjects	727.5	24		
B (Ear)	368.5	1	368.5	23.00*
AB	7.6	1	7.6	.48
B x subj w.groups	351.4	22	16.0	
Total	1279.8	47		

* $p<.001$

Experiment 4 Appendix 4.1

Data for individual subjects.
Mean reaction time (msec) for each subject for each ear for each of the two experimental tasks: (1) multiple target condition; (2) single target condition.
Male Subjects

Multiple target condition			Single target condition		
	Left Ear	Right Ear		Left Ear	Right Ear
1.	668.5	792.4	1.	362.0	420.9
2.	958.7	1014.3	2.	548.2	540.5
3.	794.3	742.7	3.	277.1	273.4
4.	914.7	857.7	4.	583.5	455.3
5.	770.7	821.2	5.	361.5	460.1
6.	999.9	927.9	6.	647.4	593.2
7.	739.3	710.2	7.	379.3	297.5
8.	741.2	657.5	8.	448.6	226.5
9.	870.8	791.1	9.	701.4	556.4
10.	650.0	638.8	10.	207.9	311.2
11.	798.8	767.9	11.	460.3	446.4
12.	935.9	691.3	12.	488.8	440.6
13.	799.5	771.2	13.	557.3	327.8
14.	748.8	761.6	14.	448.5	245.3
15.	658.5	557.0	15.	331.3	302.3
16.	728.9	734.1	16.	284.6	234.0

Data for individual subjects.
Mean reaction time (msec) for each subject for each ear for each of the two experimental tasks: (1) multiple target condition; (2) single target condition.
Female Subjects

Multiple target condition			Single target condition		
	Left Ear	Right Ear		Left Ear	Right Ear
1.	720.1	826.9	1.	233.3	296.3
2.	882.9	802.4	2.	527.9	339.3
3.	697.7	660.4	3.	629.3	398.1
4.	815.6	943.7	4.	592.5	462.0
5.	739.4	712.8	5.	304.3	267.5
6.	677.2	592.7	6.	528.1	205.0
7.	912.2	741.3	7.	354.0	323.1
8.	820.8	722.3	8.	417.7	408.2
9.	704.3	628.4	9.	357.5	235.3
10.	699.1	602.4	10.	440.8	464.3
11.	771.0	828.3	11.	446.6	521.6
12.	788.9	865.7	12.	506.1	337.9
13.	905.8	700.5	13.	373.0	244.4
14.	702.8	745.1	14.	408.1	308.2
15.	752.2	869.7	15.	470.0	545.9
16.	815.2	860.9	16.	530.5	634.7

Experiment 4 Appendix 4.2

Data for individual subjects, showing:

(i) Standard deviation (SD) of mean reaction time (msec) for each ear in each task;

(ii) number of responses (N) upon which mean and standard deviation are based. Maximum possible number of responses for each entry for multiple target condition = 30 and for single target condition = 40.

Male Subjects

Multiple target condition					Single target condition				
	Left Ear		Right Ear			Left Ear		Right Ear	
	SD	N	SD	N		SD	N	SD	N
1.	138.3	26	201.8	29	1.	133.0	39	188.8	40
2.	251.8	26	219.5	23	2.	230.5	39	272.5	38
3.	229.2	26	175.6	30	3.	114.1	40	134.8	40
4.	242.9	27	260.9	27	4.	196.0	39	149.6	38
5.	246.8	30	212.3	29	5.	178.2	37	266.5	39
6.	230.1	19	269.9	26	6.	247.1	37	250.8	38
7.	223.0	29	267.9	25	7.	209.6	39	146.5	40
8.	275.2	28	249.2	29	8.	233.8	36	122.1	40
9.	277.6	29	253.9	28	9.	299.9	39	246.9	37
10.	179.6	29	125.3	29	10.	133.8	39	124.6	39
11.	239.5	29	218.3	30	11.	176.5	35	354.9	39
12.	221.0	30	199.0	30	12.	168.7	40	190.7	39
13.	265.1	28	241.7	29	13.	208.8	39	131.8	38
14.	231.8	29	214.2	30	14.	101.2	35	148.4	40
15.	178.4	30	174.5	30	15.	152.4	39	92.7	38
16.	195.6	27	323.2	30	16.	119.2	39	141.5	39

Data for individual subjects, showing:

(i) Standard deviation (SD) of mean reaction time (msec) for each ear in each task;

(ii) number of responses (N) upon which mean and standard deviation are based. Maximum possible number of responses for each entry for multiple target condition = 30 and for single target condition = 40.

Female Subjects

Multiple target condition					Single target condition				
	Left Ear		Right Ear			Left Ear		Right Ear	
	SD	N	SD	N		SD	N	SD	N
1.	214.8	30	236.1	30	1.	92.8	38	165.2	40
2.	203.0	29	192.2	30	2.	192.8	40	111.1	40
3.	291.2	29	320.3	25	3.	299.2	32	223.8	36
4.	179.6	26	261.0	26	4.	184.9	40	186.8	39
5.	201.4	28	235.8	30	5.	134.7	39	123.8	39
6.	259.7	29	220.9	30	6.	159.7	37	99.2	39
7.	293.2	26	232.8	27	7.	152.8	37	101.6	38
8.	244.6	27	204.4	28	8.	147.4	40	156.3	39
9.	269.8	29	246.7	29	9.	209.0	38	128.7	38
10.	199.7	29	167.8	29	10.	220.9	38	266.8	38
11.	262.7	28	230.7	27	11.	215.1	40	180.0	40
12.	217.9	27	285.2	30	12.	174.1	40	213.8	40
13.	251.9	29	189.2	26	13.	159.5	40	152.2	40
14.	166.1	23	281.6	24	14.	131.2	38	141.2	39
15.	265.9	25	282.6	25	15.	179.8	40	209.7	40
16.	213.4	28	234.2	29	16.	175.6	38	229.8	38

Experiment 4 Appendix 4.3

Analysis of variance table showing effects of sex of subject (A), task (single target or multiple target) (B) and ear to which target stimuli were presented (C).

Source	SS	df	MS	F
Between subjects	971485.0	31		
A (Sex)	2948.2	1	2948.2	.09
Subj w.groups	968536.8	30	32284.6	
Within subjects	4839270.1	96		
B (Task)	4202644.1	1	4202644.1	552.80**
AB	1244.3	1	1244.3	.16
B x subj w.groups	228056.6	30	7601.9	
C (Ear)	66955.1	1	66955.1	9.36*
AC	36.4	1	36.4	
C x subj w.groups	214654.0	30	7155.1	
BC	12029.9	1	12029.9	3.20
ABC	1323.0	1	1323.0	
BC x subj w.groups	112326.7	30	3744.2	
Total	5810755.1	127		

* .01>p>.001

** p<.001

Experiment 5

Appendix 5.1

Data for individual subjects.

Mean reaction time (msec) for each ear for each of the two experimental conditions: (i) manual recognition task with no secondary task; (ii) manual recognition task with secondary verbal task.

	No secondary task		With secondary task	
	Left Ear	Right Ear	Left Ear	Right Ear
Male subjects				
Right hand 1.	322.7	273.1	382.2	307.1
response 2.	282.0	235.3	422.8	341.3
Left hand 3.	379.5	298.9	489.6	440.9
response 4.	472.9	433.5	542.1	524.6
Female subjects				
Right hand 5.	339.9	272.1	576.8	533.8
response 6.	469.3	322.1	647.9	522.6
Left hand 7.	216.8	159.6	405.0	356.9
response 8.	405.9	297.0	558.1	606.0
Subjects showing LEA.				
Male subject:				
Left hand response 9.	342.1	343.7	479.5	551.7
Female subject:				
Right hand response 10.	532.5	607.2	533.2	619.5
Female subject:				
Right hand response 11.	394.9	498.9	538.4	639.1

Experiment 5 Appendix 5.2

Data for individual subjects, showing:

(i) Standard deviation (SD) of mean reaction time (msec) for each ear in each task;

(ii) number of responses (N) upon which mean and standard deviation are based. Maximum possible number of responses for each entry = 20.

		No secondary task				With secondary task			
		Left Ear		Right Ear		Left Ear		Right Ear	
		SD	N	SD	N	SD	N	SD	N
Male subjects									
Right hand	1.	142.8	20	197.8	20	137.3	19	120.7	20
response	2.	111.9	20	96.1	20	142.1	19	122.9	20
Left hand	3.	134.6	20	105.4	20	99.3	16	134.8	17
response	4.	122.9	20	118.1	20	172.4	20	121.5	20
Female subjects									
Right hand	5.	143.3	19	190.8	20	175.5	17	162.3	19
response	6.	222.4	19	73.4	20	185.4	15	196.1	18
Left hand	7.	90.0	20	71.1	20	134.6	19	97.2	20
response	8.	136.1	20	87.1	20	135.8	17	153.1	20
Subjects showing LEA.									
Male subject:									
Left hand response	9.	140.4	20	108.9	20	175.6	16	182.0	18
Female subject:									
Right hand response	10.	160.5	20	173.1	20	181.6	19	162.1	15
Female subject:									
Right hand response	11.	132.2	20	180.3	20	144.7	16	197.2	17

Experiment 5 | Appendix 5.3

Analysis of variance table showing the effect of sex of subject (A), task (with or without secondary task) (B), hand used to make the response (C) and ear to which target stimulus was presented (D).

Source	SS	df	MS	F
Between subjects	192556.5	7		
A (Sex)	9156.5	1	9156.5	
C (Hand)	3534.3	1	3534.3	
AC	89750.2	1	89750.2	3.98
Subj w.groups	90115.5	4	22528.9	
Within subjects	273735.7	24		
B (Task)	191750.8	1	191750.8	118.14***
AB	29506.2	1	29506.2	18.18*
BC	52.8	1	52.8	
ABC	332.2	1	332.2	
B x subj w.groups	6492.3	4	1623.1	
D (Ear)	30547.8	1	30547.8	29.30**
AD	381.5	1	381.5	
CD	2515.2	1	2515.2	
ACD	706.0	1	706.0	
D x subj w.groups	4170.3	4	1042.6	
BD	1327.4	1	1327.4	
ABD	1500.2	1	1500.2	
BCD	1700.8	1	1700.8	2.47
ABCD	0.8	1	0.8	
BD x subj w.groups	2751.4	4	687.9	
Total	466292.2	31		

* $.05>p>.01$
** $.01>p>.001$
*** $p<.001$

Experiment 6 (i)

Appendix 6.1

Data for individual subjects showing mean reaction time (msec) for each ear in the two conditions: (i) attention not directed; (ii) attention directed to either right or left ear.

		Attention not directed		Attention directed	
		Left Ear	Right Ear	Left Ear	Right Ear
Male subjects:	1.	292.3	192.7	322.5	282.5
Right hand	2.	465.7	420.6	349.5	333.9
response	3.	565.5	394.4	434.8	433.5
	4.	391.0	289.2	337.4	261.8
Male subjects:	5.	453.5	289.8	384.8	355.8
Left hand	6.	431.2	381.7	459.2	349.9
response	7.	656.4	516.9	457.5	348.7
	8.	337.3	281.9	296.8	259.0
Female subjects:	9.	435.6	373.6	352.5	318.7
Right hand	10.	357.5	298.8	337.0	250.9
response	11.	521.4	435.7	434.5	424.0
	12.	523.2	269.7	423.7	326.5
Female subjects:	13.	456.2	441.7	413.8	344.5
Left hand	14.	342.2	311.6	228.3	208.9
response	15.	433.7	383.8	306.2	331.6
	16.	570.1	364.2	421.6	356.4
Subjects showing LEA:					
Male subjects:	17.	326.2	356.9	352.0	376.5
Right hand response	18.	410.9	418.0	395.4	408.9
Female subjects:	19.	257.5	287.2	345.9	312.6
Right hand response	20.	343.8	386.5	393.1	400.2
Female subjects:	21.	418.2	456.2	444.7	462.4
Left hand response	22.	431.2	454.5	370.2	392.5

Experiment 6(i)

Data for individual subjects, showing:

(i) Standard devisation (SD) of mean reaction time (msec) for each ear in each condition
(ii) number of responses (N) upon which mean and standard deviation are based. Maximum possible number of responses for each entry = 20 for the non-directed condition and 40 for the directed condition.

N.B. An asterisk appears several times in the (N) column. Where it appears it indicates that the number of responses was in fact three more than the number given for that entry. The mean and standard deviation were calculated on the number given but 3 should be added to these entries to give an accurate figure for the omissions.

		Attention not directed				Attention directed			
		Left Ear		Right Ear		Left Ear		Right Ear	
		SD	N	SD	N	SD	N	SD	N
Male subjects: Right hand response	1.	129.9	19	81.8	19	116.1	34*	139.0	40
	2.	177.6	20	135.9	20	108.4	39	128.9	36*
	3.	146.4	20	115.6	20	123.1	37	112.5	38
	4.	110.5	18	134.3	20	126.7	39	111.7	39
Male subjects: Left hand response	5.	131.7	19	124.0	20	156.4	39	109.8	37*
	6.	103.3	20	83.1	20	148.7	37*	132.4	39
	7.	153.0	19	157.8	20	99.1	39	116.3	40
	8.	72.8	19	109.0	20	109.6	40	81.1	40
Female subjects: Right hand response	9.	183.1	16	184.3	19	104.0	40	82.6	39
	10.	154.6	20	157.3	19	142.8	39	98.8	40
	11.	153.3	20	113.3	20	138.2	38	108.1	40
	12.	153.1	18	94.9	20	93.5	39	82.6	40
Female subjects: Left hand response	13.	192.1	20	133.3	20	140.3	37*	121.8	39
	14.	117.0	19	130.2	20	97.7	39	113.3	40
	15.	192.2	18	114.9	18	99.3	39	152.5	40
	16.	134.1	18	78.5	20	124.9	40	99.2	39

Experiment 6(i)

		Attention not directed				Attention directed			
		Left Ear		Right Ear		Left Ear		Right Ear	
		SD	N	SD	N	SD	N	SD	N
Subjects showing LEA:									
Male subjects:	17.	96.1	20	83.0	20	124.7	39	95.8	40
Right hand resp.	18.	132.4	18	130.0	18	130.1	37	185.6	37
Female subjects:	19.	144.7	18	176.6	19	117.6	40	125.2	40
Right hand resp.	20.	107.4	19	136.3	20	112.2	36	95.0	37
Female subjects:	21.	125.4	19	186.7	19	100.8	38	146.3	40
Left hand resp.	22.	86.1	20	177.2	20	122.5	40	106.4	40

Experiment 6(i)

Appendix 6.3

Analysis of variance table showing effects of sex of subject (A), condition (attention directed or not directed) (B), hand used to make the response (C) and ear to which stimulus was presented (D).

Source	SS	df	MS	F
Between subjects	271503.0	15		
A (Sex)	13.7	1	13.7	
C (Hand)	1646.3	1	1646.3	
AC	6839.3	1	6839.3	
Subj w.groups	263003.7	12	21917.0	
Within subjects	236979.7	48		
B (Condition)	46893.9	1	46893.9	14.65 **
AB	1885.7	1	1885.7	
BC	4323.1	1	4323.1	1.35
ABC	415.2	1	415.2	
B x subj w.groups	38411.4	12	3201.0	
D (Ear)	87025.0	1	87025.0	40.52 ***
AD	248.8	1	248.8	
CD	207.4	1	207.4	
ACD	2512.5	1	2512.5	
D x subj w.groups	25772.0	12	2147.7	
BD	10327.6	1	10327.6	6.88 *
ABD	0.3	1	0.3	
BCD	768.7	1	768.7	
ABCD	162.5	1	162.5	
BD x subj w.groups	18025.6	12	1502.1	
Total	508482.7	63		

* $.05 > p > .01$
** $.01 > p > .001$
*** $p < .001$

Experiment 6(i) Appendix 6.4

Further analysis of the condition x ear (BD) interaction.

Source	SS	df	MS	F
Between ears in Condition 1	78655.7	1	78655.7	43.1 **
Between ears in Condition 2	18696.9	1	18696.9	10.3 *
Error		24	1824.9	
Between Conditions for the right ear	6603.9	1	6603.9	2.8
Between Conditions for the left ear	50617.6	1	50617.6	21.5 **
Error		24	2351.5	

* $.01 > p > .001$

** $p < .001$

Experiment 6 (ii) Appendix 6.5

Data for individual subjects showing mean reaction time (msec) for each ear in each condition:
(i) attend to right or to left ear; no secondary task;
(ii) attend to right or to left ear, perform secondary task.

		No secondary task		With secondary task	
		Left Ear	Right Ear	Left Ear	Right Ear
Male subjects	1.	298.5	233.1	306.0	284.0
	2.	352.2	232.0	553.9	563.1
	3.	401.3	317.4	428.8	392.9
	4.	317.3	230.6	501.4	526.8
	5.	403.8	354.5	698.7	560.3
	6.	334.3	303.9	584.4	481.1
Female subjects	7.	205.6	185.6	460.4	361.2
	8.	402.1	261.0	607.8	498.6
	9.	424.5	400.3	620.0	533.0
	10.	261.0	258.5	496.2	452.4
	11.	443.2	336.1	567.0	540.7
	12.	360.3	311.4	629.0	613.3
Male subject showing LEA.	13.	249.1	259.5	371.2	411.8

Experiment 6(ii) Appendix 6.6

Data for individual subjects, showing:

(i) Standard deviation (SD) of mean reaction time (msec) for each ear in each condition;

(ii) number of responses (N) upon which mean and standard deviation are based. Maximum possible number of responses for each entry = 30.

		No secondary task				With secondary task			
		Left Ear		Right Ear		Left Ear		Right Ear	
		SD	N	SD	N	SD	N	SD	N
Male	1.	91.5	29	82.9	30	97.3	30	93.9	30
subjects	2.	121.7	30	78.8	30	155.0	27	127.6	29
	3.	105.0	29	145.1	30	145.7	28	200.9	29
	4.	131.9	29	110.2	29	175.6	24	164.1	27
	5.	105.9	30	128.1	29	165.6	27	170.8	28
	6.	164.0	30	139.2	30	176.2	26	187.8	24
Female	7.	82.4	30	68.0	30	91.1	29	106.0	30
subjects	8.	126.0	30	92.7	30	197.3	28	159.5	25
	9.	108.3	29	112.0	30	167.8	22	143.2	25
	10.	79.3	29	82.3	30	195.4	29	145.4	30
	11.	160.4	30	87.6	29	176.4	23	191.0	26
	12.	114.0	30	97.9	30	93.1	24	113.8	26
Male subject showing LEA.	13.	92.0	30	82.5	30	150.6	27	129.6	28

Experiment 6(ii) Appendix 6.7

Analysis of variance table showing effects of sex of subject (A), condition (with or without secondary task) (B), and ear to which stimuli were presented (C).

Source	SS	df	MS	F
Between subjects	227064.1	11		
A (Sex)	6742.6	1	6742.6	
Subj w.groups	220321.5	10	22032.2	
Within subjects	585184.1	36		
B (Task)	447084.5	1	447084.5	67.4 *
AB	3807.5	1	3807.5	
B x subj w.groups	66333.3	10	6633.3	
C (Ear)	42358.1	1	42358.1	48.4 *
AC	12.2	1	12.2	
C x subj w.groups	8757.9	10	875.8	
BC	371.3	1	371.3	
ABC	903.8	1	903.8	
BC x subj w.groups	15555.5	10	1555.6	
Total	812248.2	47		

* $p<.001$